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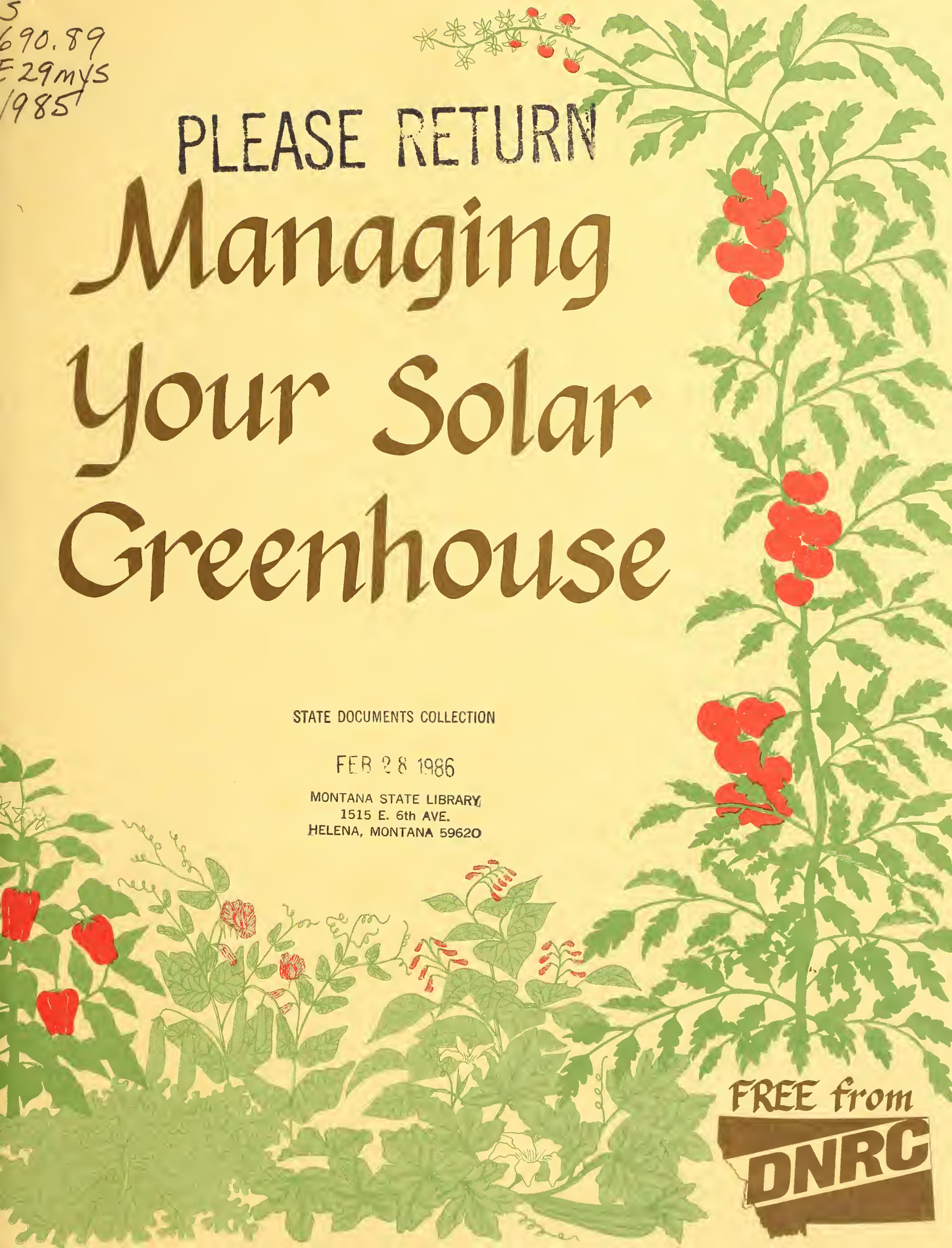

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MANAGING YOUR SOLAR GREENHOUSE

ENERGY DIVISION
DEPARTMENT OF
NATURAL RESOURCES
AND CONSERVATION
CAPITOL STATION
HELENA, MT 59620

AUGUST 1985

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DNRC would like to thank the many Montanans who helped us put out this publication by letting us into their homes and greenhouses.

CHAPTER 1

Understanding the Greenhouse Environment

If you're a gardener in Montana, you're familiar with the short growing seasons, and you've probably adapted your gardening techniques—and taste buds—to fit Montana's climate. Some Montanans, though, extend and expand their growing seasons by using a solar greenhouse. With a solar greenhouse, you can start seedlings earlier in the season, produce plants to maturity in the spring and fall, and even grow your favorite crops year-round.

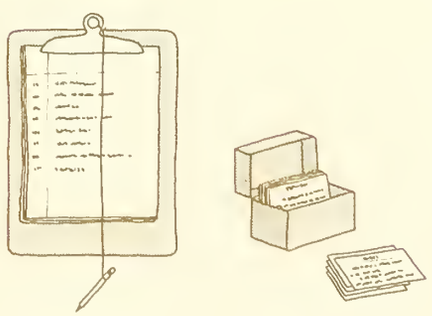
A solar greenhouse is designed to make the most of the sun's rays by using large areas of south-facing glazing. Solid, well-insulated walls—usually on the north and west sides of the solar greenhouse—reduce heat loss. Thermal mass, such as water, rock, or soil, retains the heat collected during the day. This heat is released at night, or when temperatures drop.

Your solar greenhouse can be free-standing, or attached to another structure, such as your home. You can use your solar greenhouse as a food producer, heat producer, or both. This publication will focus on the solar greenhouse as a food producer.

Naturally, the design and construction of the solar greenhouse will influence its performance, but even in the harshest of Montana's climates the solar greenhouse has proven its ability to function as a year-round food producer.

Keeping Track

Keeping good thermal and horticultural greenhouse records will provide you with valuable information for the future. Don't leave this information to your memory; write down your observations. A clipboard posted in the greenhouse is handy for keeping data. Once each sheet is filled it can be hole-punched and stored in a notebook for future reference. Index cards and a file box also work well for record keeping.



Keep track of horticultural data, such as planting dates, varieties of crops, harvest dates and yields, pest problems, and other observations. Thermal data should include high and low daily temperatures, preferably both interior and exterior. It can be fun to "wax eloquent" about the wonders of your greenhouse, extreme weather conditions, or on-the-spot theories. More than anything else you will be gaining information for future production, as well as a better understanding of your greenhouse as an environment.

The goal of the solar greenhouse is to attain some level of horticultural production. With an understanding of what plants need to grow and the basic processes that allow them to continue growing, you can better understand the greenhouse as an environment suitable for producing food.

How Plants Grow: Physiological Processes

For plants to fully develop, certain conditions must be present in any environment. These conditions include light, a certain range of temperatures, water, carbon dioxide, humidity, and available nutrients. For best results, these conditions must not only be present, but present in the proper proportions. If one of these necessary parts is not present or is in short supply, the growth of the plant will be limited to that extent. This lacking condition is commonly referred to as the "limiting factor."

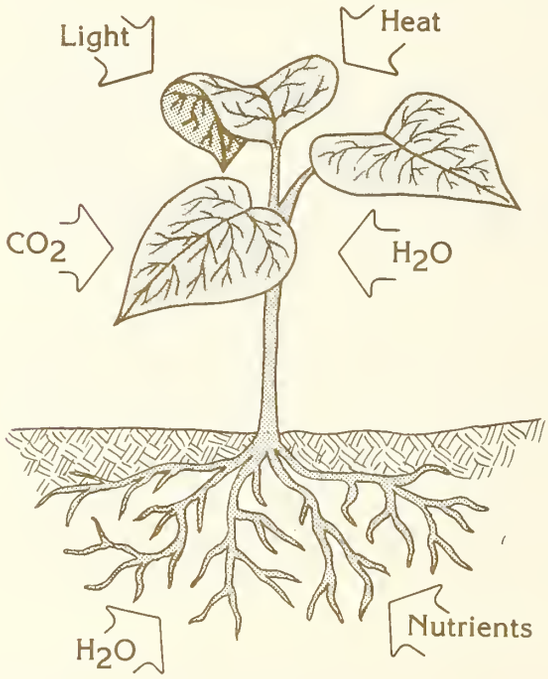


Figure 1. Limiting factors for plant growth and development.

Photosynthesis has been described as the most important chemical reaction of all plant functions, and provides an excellent illustration of the principle of limiting factors. Without the ability of green plants to manufacture food (carbohydrates), the world as we know it could not exist.

To better understand how limiting factors affect plant growth, an examination of the basic physiological processes of a plant is helpful. Plants, like animals, have a variety of metabolic processes and responses to their environment. Among these are photosynthesis, respiration, transpiration, translocation, and physical changes such as flower, fruit, and tuber development.

Photosynthesis is the combination of water (H_2O) and carbon dioxide (CO_2) in the presence of light and chlorophyll to produce carbohydrates ($C_6H_{12}O_6$) and release oxygen (O_2). Water, carbon dioxide, chlorophyll, heat, and certain portions of the light spectrum must be present for photosynthesis to proceed. If any of these factors is in short supply, the photosynthetic process will be slowed. Plant growth depends on the carbohydrates produced in photosynthesis as its energy source. For the best growth to continue, all photosynthetic components must be available to the plant in proper proportions.

There are no set environmental conditions for all plants—different species and varieties have different needs. Some plants require higher temperatures to trigger the photosynthetic process. Similarly, responses to different light intensities differ according to species and variety. Despite differing needs, however, all plants must have carbon dioxide, water, heat, and light present at the same time to carry out photosynthesis. Consequently, photosynthesis ceases in the dark.

Respiration is carried out on a continual basis. Sometimes considered the reverse of the photosynthesis reaction, respiration is the combination of carbohydrates (those produced during photosynthesis) and oxygen, which produces water and carbon dioxide.

Respiration releases energy stored in the carbohydrates for use in other metabolic activities such as cell division, nutrient absorption, and translocation. Higher temperatures increase the rate of respiration. Light does not affect respiration except to the extent that it contributes heat; hence, respiration continues day and night.

Transpiration is the loss of water through stomata , the openings in the leaf surfaces. Under normal conditions the stomata remain open in response to the presence of light, and allow carbon dioxide to enter the leaf (for use in photosynthesis). Transpiration occurs because of the difference in water pressure within the plant leaf and the surrounding air. The amount of moisture lost during transpiration depends on many conditions, such as the temperature of the leaf surface and the surrounding air, the humidity in the air, the movement of air across the surface of the leaf, and the amount of water available to the plant at the roots. Wilting is a protective response of a plant that has lost too much water through transpiration. Wilted leaves lose their turgor (rigidity), causing the stomata to close, thus preventing further water loss.

Translocation is the movement of nutrients (minerals) that have been absorbed, in solution, through the roots to the various parts of the plant. Translocation is also the movement of the carbohydrates manufactured during photosynthesis. The transport system for this process is the movement of water through the tubular xylem cells. If the availability of water is limited, translocation of the minerals and carbohydrates will also be limited and growth will slow down or stop.

Physical developments, such as flower, fruit, and tuber formation, are affected by specific environmental conditions. In combination with photosynthesis, respiration, transpiration, and translocation these processes allow a plant to grow and develop.

The "photoperiod" response that causes flowering is one such development. Photoperiod denotes the amount of light (in hours) that a plant receives. ("Photo" means light.) Flowers bud in many plants only when specific light conditions are present. A short-day plant is one that flowers under light conditions of (usually) less than 12 hours per day. A long-day plant is one that flowers because of long photoperiods (usually more than 12 hours per day). Plants that do not flower as a response to light are called day-neutral plants. The specific crop produced in your greenhouse will determine whether short-day or long-day conditions are preferable. Other conditions may have a more critical role, as in the case of day-neutral plants. For example, Chinese cabbage is produced for its leafy green vegetation, and is a long-day plant; it will flower and go to seed as a response to long-day conditions. Therefore, grow Chinese cabbage in Montana during the shorter days of late fall, winter, and early spring for best results.

For day-neutral plants, other environmental factors have a greater influence on flowering. Temperature is most often the critical factor. Tomatoes, a day-neutral plant, need temperatures no lower than 58°F in order to flower and set fruit. Day length has no effect on flowering in tomatoes, however, and tomatoes will flower under a variety of day-length conditions as long as the temperature remains in the correct range.

The relationship between light and temperature is critical for some plants that require the proper mix of light and temperatures to flower. An example is the carrot, which requires both long days and low temperatures to flower.

Other physical developments, such as tuber formation, are also due to responses to the environment. The root bulb formation of beets and onions, for example, is extremely slow in cool conditions. Beets and onions grown in the greenhouse during the cooler seasons will not readily form root bulbs, but can be grown for their greens.

With a clearer understanding of how physiological processes and limiting factors influence the growth and development of plants, you are ready to further consider the effect of the environment being created by your solar greenhouse.

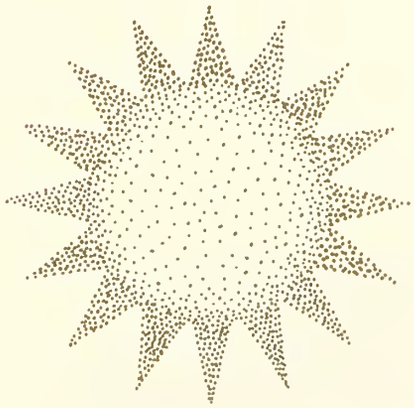
CHAPTER 2

The Solar Greenhouse Seasons

Because of peculiarities of design, orientation, and climatic conditions, your solar greenhouse will have its own set of "seasons." You can determine these seasons by observing, monitoring temperatures and light, and experimenting. Prepare yourself for a few disappointments along the way. But later, when you're accustomed to your greenhouse's seasons, you can have a successful garden to enjoy for years to come.

The following discussion of the various seasons includes some generalities, but it should give you some insights for timing and selecting crops. Appendix 2 on page 38 includes more information on specific crops. After you have gained some experience and information on the thermal performance of your greenhouse, these data should be even more useful.

Summer—May to September



Summer usually means your outdoor garden is in full swing, but the heat-loving vegetables and fruits, such as tomatoes, eggplant, cucumbers, melons, and peppers, just don't produce adequately, if at all, in many places in Montana. A solar greenhouse can provide the conditions necessary to produce these heat- and light-loving crops without damage from frost or hail.

Tomatoes, peppers, eggplant, melons, and cucumbers all require high temperatures for best germination. Seed these crops 6-8 weeks before they are transplanted to their permanent places in the greenhouse. This could mean sowing seeds during March for setting out in May. Because night temperatures could still be quite low in March in the greenhouse, take special care to provide a proper germination area for these crops. (See Germination, page 25.) Cucumbers and melons don't transplant well from flats. They are best seeded into individual pots or peat pots.

Grow tomatoes, cucumbers, and melons vertically for the best use of space and light. Melons do well on trellises with slings of fabric used to support the fruit as it develops. Attach tomato and cucumber vines to strings fastened to overhead wires, and train them to a single stem by pruning suckers or side shoots. This technique provides good production and uses more available light by reducing the foliage. Leave several extra feet of string or twine at the wire, so you can lower the plants after the vegetables have been harvested

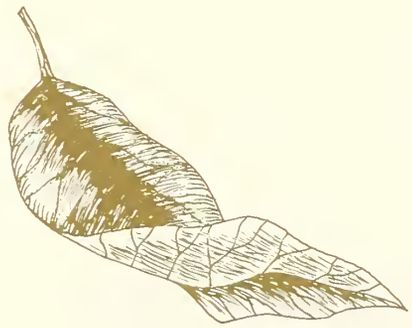
from the lower clusters. Prune the bottom of the stem of all growth. If you bury the stem after it is lowered, new roots may be produced.

Both tomatoes and cucumbers need to be pollinated in order to produce. However, all female cucumbers are self-pollinating; these are most commonly used in greenhouses these days. Pollinate tomatoes by gently vibrating the flowers—either directly or by gently shaking the twine on which they're trained. Tomato pollination is most successful on sunny days when the pollen is shedding between 10 a.m. and 2 p.m., and should be done regularly. Varieties of cucumbers that are not self-pollinating can be pollinated by brushing pollen from male to female flowers with a small dry paint brush.

Arrange your greenhouse crops so that each will benefit from the available sunlight. For example, place the plants that will grow tall and have a lot of foliage toward the north wall. This way, the shorter plants and those with less foliage won't be shaded by the larger plants.

Pole or bush beans could be an appropriate summer greenhouse crop if they don't normally produce between frosts where you live. They make a good late-spring greenhouse crop, too.

Fall—September to November



Fall is the transition season. Days are getting shorter but temperatures are still generally warm. Summer crops can still produce well, especially tomatoes. For this reason, the fall greenhouse season often is an extension of the summer season in terms of crop production. But there are several crops that do quite well in the fall greenhouse season. Having these crops ready to go as transplants to replace summer crops, which no longer produce satisfactory yields, is an efficient scheduling technique.

Broccoli, cauliflower, Chinese cabbage, and kohlrabi are all good "filler" crops for the fall greenhouse. Seed these in flats in mid-July to mid-August. Broccoli is an especially good choice since it will produce several more heads after the main one is cut. (Cauliflower only produces one head per plant.) You can seed crops like radishes, peas, and beets directly in spots with adequate light. Radishes are a great "filler" crop because they grow fast.

Before you get too carried away with fall crops you should realize the relationship between the fall season and the winter crop, if you are planning year-round production in your greenhouse. The end of the fall season (mid-October to November) is the time to establish the winter crop. Getting the winter crops established and growing before the severe cold comes is the key to winter greenhouse production.

Winter—December to Mid-February

Everything slows down in the greenhouse during the winter season (except perhaps the whitefly populations). Plant growth is very slow due to low temperatures and low light levels. Freezing temperatures are common inside a greenhouse that has no backup heat. The choice of crops is reduced to the most hardy vegetables. But your diet need not be boring. Winter greenhouse crops include leafy green vegetables such as chard, corn salad, kale, parsley, Chinese greens, leaf lettuce (including romaine), endive, mustard greens, and chicory. Chinese cabbage and butterhead lettuces can be picked a little by the "sustainable yield" method, mentioned in "Crop Selection and Scheduling," but if you overpick they won't "head" up. Snowpeas, green onions, collards,

and radishes are also suitable winter crops. (Don't expect snow peas to flower until spring.)

Sow Chinese cabbage, Brussels sprouts, kale, the lettuces, and endive in flats in early September to October, and set out in the greenhouse 4-6 weeks later. Remember, you want the crops to be almost edible size before the coldest weather and shortest days. Lettuce crops have been successfully seeded and grown throughout the winter months in many northern-climate solar greenhouses. Again, your particular conditions will dictate whether this is possible. Other members of the cabbage family, including cabbage, kohlrabi, broccoli, and cauliflower, have done quite well in winter conditions in northern-climate greenhouses across the United States.

Spring—Mid-February to April

Mid-February may not seem like spring in Montana. But in the greenhouse, light levels are beginning to increase noticeably as the days lengthen; this time marks a change of season. Nighttime lows in your greenhouse may still be below freezing, but the increasing daylight means increasing production.

Many of the early spring crops are the same ones grown during the winter season. Begin successive plantings of lettuce, endive, kale, Chinese greens, collards, radishes, green onions, chard, corn salad, spinach, and New Zealand spinach in mid-to-late February. You can also sow beets and turnips, but tuber development will be small; grow them for their greens. (Warmer temperatures and longer days are necessary for good tuber development in these crops.) Start strawberry plants now in pots to save space in your beds. They do well in hanging baskets. Fava (broad) beans are quite hardy, and do well in the greenhouse now. Place them to the back (north) of the greenhouse because they can grow up to three feet high.

When nighttime temperatures in your greenhouse are no longer dropping below freezing—sometime around the middle of March—you can plan more exciting crops: summer squash, carrots, or beans (bush and pole). Bush squash take up a large space, but one or two plants will produce a good deal of food. Imagine eating homegrown squash in May!

Spring is traditionally the busy season in commercial greenhouses, and probably will be the same in yours. Spring means it's time to think about outdoor gardens in Montana. Using your solar greenhouse as a season extender

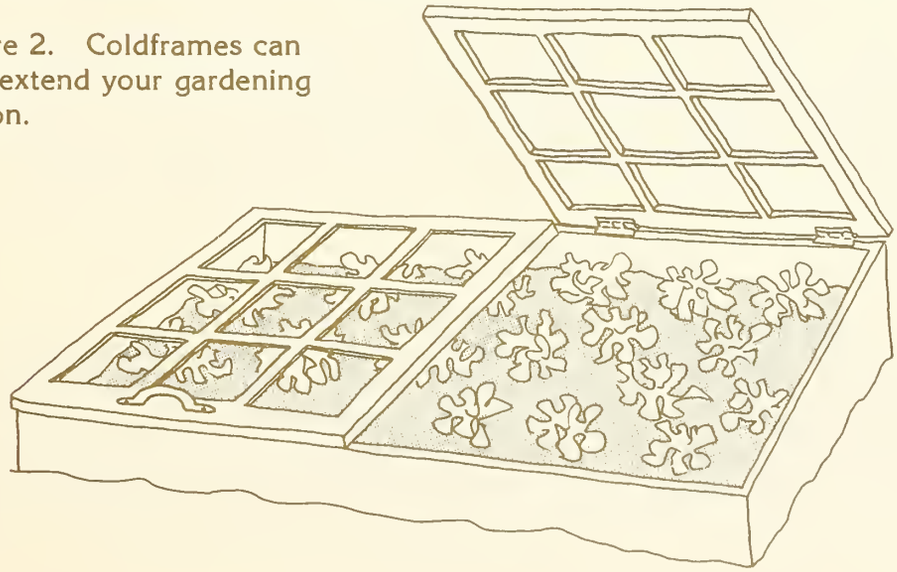


Figure 2. Coldframes can help extend your gardening season.

can speed those thoughts into production. As a seedling house in combination with a garden and coldframe (see Figure 2), your solar greenhouse is in its prime in these cooler, northern climates. You can produce seedlings (starts) for both coldframes and the garden and can add 6 to 8 weeks or more to your outdoor growing season. Starts need to be "hardened off"—adjusted to coldframe or outdoor conditions. Do this gradually by moving the seedlings into the coldframe during the day and back into the greenhouse in the evening for several days. Then begin leaving them out in the coldframe overnight. After several more days, transplant your starts either into the garden or into the coldframe. If you don't have a coldframe, move your seedlings outside during the day to a spot somewhat sheltered from winds. After several days of this, move them to a more exposed location for a couple of days, then into the garden. A word of caution: don't get overly eager to get your plants out. Pay attention to frost dates for your area. If you set out frost-sensitive plants and they freeze, you will lose six or more weeks of growing time. Set out frost-hardy plants, once they have been hardened off, as soon as the ground has warmed and can be worked.

Plant Varieties

Not all plants do well in solar greenhouses with their light limitations and widely fluctuating temperatures. In addition, of the crops that do tolerate these conditions, there are some varieties that do better than others. Select and plant varieties that can best tolerate these conditions. For now, choose commercially available varieties that do best under these conditions.

In Appendix 2 on page 38, varieties have been included, wherever possible, that have been reported as successful in solar greenhouses in the northern parts of the United States.

CHAPTER 3

Planning the Greenhouse Environment

A basic understanding of some biological processes and an awareness of the effects of changing environmental conditions on plant growth will help you plan your solar greenhouse environment. However, remember that each aspect is part of a system of highly related conditions; none stands alone. No amount of light will make up for a lack of temperature where photosynthesis is concerned. The evaluation of the solar greenhouse should be based on its performance as a system. Understanding the function of each component of the system will help you analyze the potential of the greenhouse.

The best time to consider the environmental system being created is during the design and planning phases. If you plan to use your greenhouse extensively for growing food, give special consideration to cost, location, and available material. Understanding the conditions that plants need to thrive will help you weigh the benefits of different design and construction details against the limitations.

The Unique Solar Greenhouse Environment

Solar greenhouses have some unique design features that affect their horticultural performance. The most notable feature is the solid north wall, and, in most cases, solid east and west walls, too. Solid walls restrict light, which affects plant growth. Another unique feature is the incorporation of thermal mass into the interior of the greenhouse, which may limit the production area. Finally, many solar greenhouses use no backup heat source. For this reason, temperatures may fluctuate widely from day to night, stressing many plants. However, you can moderate the effects of these unique features and benefit from your horticultural efforts.

Temperature

Fluctuations in temperatures in the solar greenhouse can be extreme especially between sunny days and cold, clear nights. In Montana, temperature swings of as much as 50°F have been recorded. Most plants prefer a small fluctuation between day and night temperatures—somewhere between 10°F and 15°F. Many plants can tolerate wider fluctuations but their growth is usually slowed.

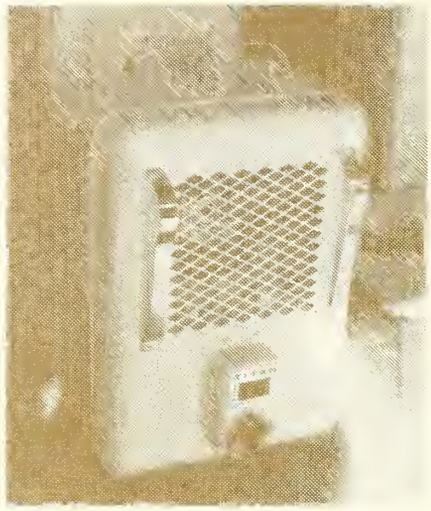


Figure 3. An electric space heater is one way to control the temperature in your solar greenhouse.

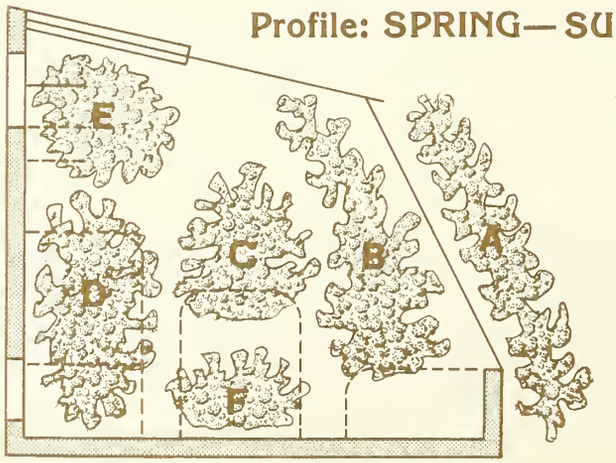
To reduce the temperature fluctuations, several options should be considered during design and construction.

- **Pay special attention** to sealing and insulating during construction to limit infiltration and air exchanges; this will help you moderate temperature extremes. Carefully seal around the glazing, doors, and vent openings. Solid walls, especially the north wall in a free-standing greenhouse, should be well insulated and protected with a vapor barrier such as polyethylene.
- **Use your attached greenhouse** with your house to control temperatures. During the day, your greenhouse can "dump" heat into your house. At night, your house can contribute heat from its heating source to the greenhouse. In this case, no thermal mass is necessary.
- **Install a thermostatically controlled heating system** (such as electric space heaters; see Figure 3). Set the thermostat at the minimum acceptable night temperature for your particular crops.
- **Use a properly installed thermal curtain** or shutter to reduce heat loss from glazed surfaces at night.
- **Use a thermal blanket** over plants inside the greenhouse to keep temperatures around the leaf surfaces warmer.
- **Grow plants in raised beds** where there is a warmer layer of air. According to Tom Harpole, a solar greenhouse owner in Avon, Montana, "raised beds are the way to go."
- **Make your beds at least 24 inches deep.** The deep beds provide a good depth for root development in most vegetable crops and also have been shown to moderate the temperature swings around the root zone area. The soil in deep beds also contributes to the thermal mass inside the greenhouse.

Light

Light is often the most limiting factor in solar greenhouse production because of the reduced area of glazing, as compared to the all-glazed, conventional greenhouse structure. The tendency with solar greenhouses has been to emphasize the thermal capabilities of the structure, often replacing glazing with solid, well-insulated walls. The result has been severely reduced light levels in the greenhouse, particularly towards the north wall. (The light levels decrease

Profile: SPRING—SUMMER—FALL



A. Shading plants.
B. Fruiters. Tomatoes, cucumbers trained up twine. Trim foliage, squash, melons.
C. Seedlings, herbs, fruiters. Hydroponic table.
D. Low light, coolest greens. In late summer new fruiters can go here. Climbers, flowers.
E. Flowers, shade lovers.
F. Berries, shade lovers.

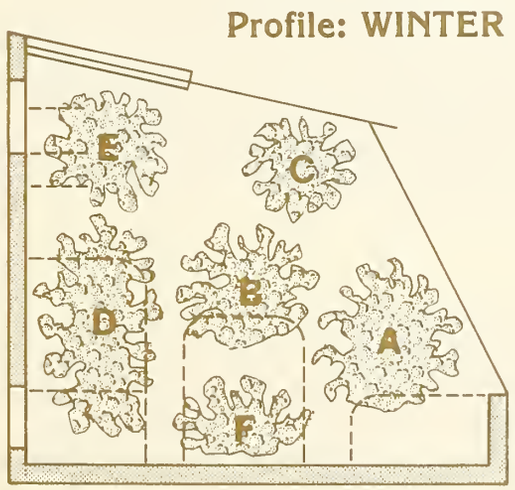
farther away from the south-facing glazing.) Because light is important for photosynthesis, it is not surprising that slower growth and lower production have been observed in the plants farthest from the glazing.

The angle of the glazing and the depth of the greenhouse greatly affect the amount of light within the greenhouse. This is particularly important during the summer months when the sun is higher in the sky. The tendency to design greenhouses with steep, south-facing glazing and no overhead glazing (to maximize solar gain and minimize heat loss) has resulted in poor light levels during the summer months. The deeper the greenhouse the more this becomes a problem because of additional areas of shading. Generally, vertical glass is recommended because you run into many problems with angled glass in a heat-producing sunspace.

- **It is difficult to shade** tilted glass, so you have less control over temperature.
- **Snow and ice** accumulate on surfaces during winter months.
- **Window insulation** is not available for glass tilted less than 45 degrees.
- **Tilted glass** is more susceptible to hail damage, vandalism, and accidents.
- **Installation** will be more expensive.
- **Glazing warranties** may be voided.
- **Installation and waterproofing** are difficult.
- **The large solar input** will lead to overheating on clear days, which could burn your plants.

Although the same problems could occur in a horticultural greenhouse, they are not as serious as in a sunspace intended to be a finished part of your house. Leakage of water from outside, for example, would be much less a concern in a horticultural greenhouse. Further, since a horticultural greenhouse generally can use all the light available, it sometimes is not necessary to provide shading.

On the other hand, it is just as necessary to prevent heat loss at night for sunspaces as for horticultural greenhouses. The installation of adequate venting also would be equally important for both types of structures. Clearly, it is important to consider all the above in designing a sunspace or greenhouse, and to make decisions based on the specific purposes you have in mind.



A. Lightest, coldest. Leafy greens, radishes, peas, broccoli, roots, tubers. Carry over fruiters.
B. Light, cool. Herbs, greens, flowers. Transplant seedlings.
C. Light, warm. Hanging pots, flowers, herbs.
D. Light, warm. Winter tomatoes, peppers. Climbers, beans, houseplants.
E. Low light, warmest. Start seeds, sprouts. (On shelves, bread will rise well here.)
F. Shady, cool. Berries.

Figure 4. Seasonal light and temperature levels in your solar greenhouse.

Adapted from *The Food and Heat Producing Solar Greenhouse,* by Bill Yanda and Rick Fisher. Copyright © 1980 by Bill Yanda and Rick Fisher. Reprinted with permission of the publisher, John Muir Publications, Santa Fe, New Mexico.

Before building, calculate when and where shaded areas will occur within the greenhouse based on the sun angle, depth, and orientation of the greenhouse, and the glazing angle. Pay particular attention to late spring, summer, and early fall conditions. Most of the summer greenhouse crops require a great deal of light for optimum production. To obtain the very best light levels, some of the following measures may be necessary.

- **Add glazing overhead** in the roof. This is most helpful for summer conditions, especially in greenhouses with steep glazing angles or vertical glazing. The overhead glazing admits light much farther into the interior when the sun is high in the sky. The glazing can be fitted with insulating panels during late fall, winter, and early spring when the sun angle is lower and there would be no direct gain. However, the problems mentioned above will also apply here.

- **Add partial glazing** to the east or west wall(s). This can contribute direct light in the morning and the late afternoon as well as add diffuse light to the greenhouse interior. In Montana's cold climate, it's generally best to choose east glazing because this allows the greenhouse to heat up as early in the day as possible to resume photosynthesis. Also, most winds prevail from the west and northwest. Exposing glazing to winds can cause more rapid heat loss due to convection.

- **Arrange interior design** and placement of growing areas to minimize shading. Beds or benches should be placed where there is little or no shading. Shaded areas could be used for purposes other than plant production such as potting benches, germination set-ups (for most plants), or additional thermal mass storage. Shade-loving foliage plants could occupy this space. Greenhouses with kneewalls will shade the south edge of the interior during certain times of the year. For this reason, build benches or beds up to the height of the kneewall.

- **Paint the interior** of the greenhouse with white paint to help diffuse light throughout the structure.

In areas of the United States where hailstorms are common, tempered glass should be used for roofing greenhouses instead of regular double-strength glass (if a glass skin has been decided upon). Untempered glass is not very safe in the overhead position whether it is exposed to hail or not.

Hail damage to plastic materials may not be immediately obvious, taking the form of dents or small surface breaks where weathering will proceed rapidly in subsequent years.

One-eighth-inch-thick tempered glass has been used effectively against hailstone impact.

Carbon Dioxide and Ventilation

The presence of carbon dioxide (CO_2) is essential to the process of photosynthesis. Carbon dioxide is available in the atmosphere at about 300 parts per million (ppm). However, in the enclosed greenhouse structure the concentration of CO_2 can deplete quickly as plants use CO_2 for photosynthesis. A "compensation point" is reached when the CO_2 given off during respiration

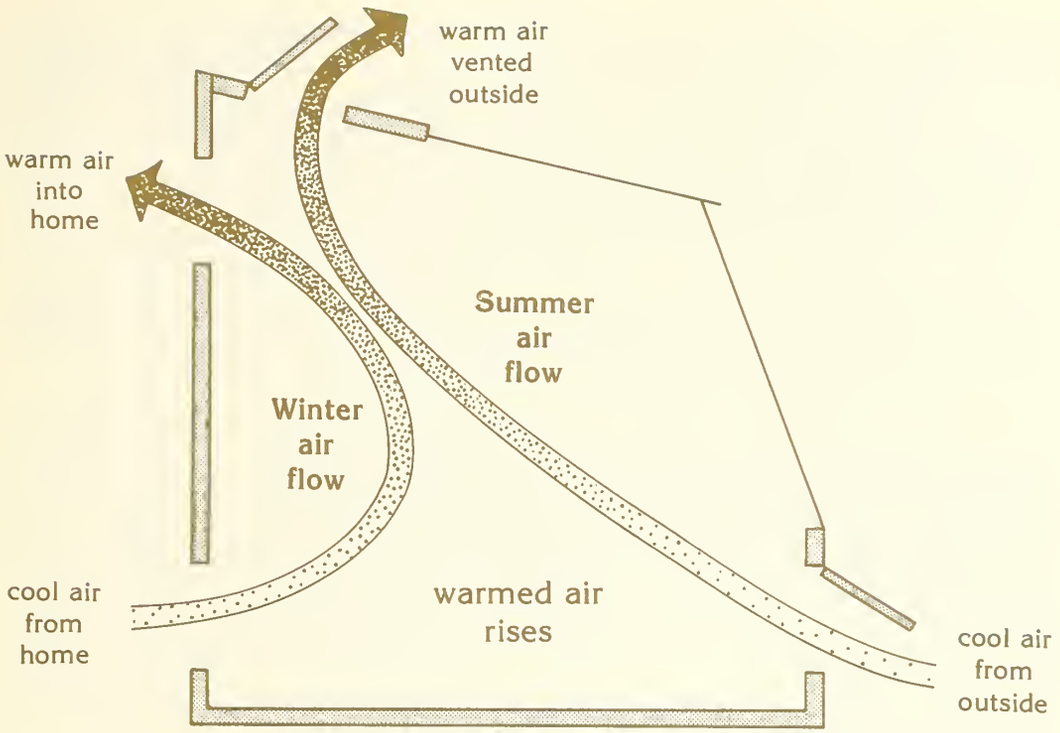


Figure 5. Air circulation in a typical attached greenhouse.

equals the CO_2 used for photosynthesis. Plant growth stops because the carbohydrates produced during photosynthesis are being depleted by the respiration process. The compensation point can often be reached early in the day in the greenhouse enclosure unless steps are taken to provide supplementary CO_2 to the environment.

The most common way to supplement CO_2 is by venting. Venting brings in air from the outside to raise the interior levels of CO_2 back up to ambient levels (300 ppm).

"Passive" venting systems such as bottom-to-ridge venting or cross ventilation (lower-to-upper) can be effective methods for moving air through the greenhouse (see Figure 5). Take advantage of prevailing winds in passive venting systems. Ratios will vary on the size of the vent openings necessary, but generally the openings are 20 to 30 percent in area of the total square footage of the greenhouse. The lower openings should be 5 percent smaller than the upper vent openings. For example, a greenhouse with 120 square feet would need 18 square feet for upper vents and 12 square feet for lower vents. The combined vent openings would equal 30 square feet, or 25 percent of the total floor area.

Several devices are available that will open and close the vents passively. These devices operate with a thermally sensitive piston filled with an expanding gas or paraffin. When the temperature reaches the "triggering" point, depending upon the particular device, the expansion in the piston pushes an armature that is connected to and opens the vent (see Figure 6). These thermal vent openers are available in several temperature-sensitive ranges. Some have adjustable temperature settings. They can lift from 7 to 30 pounds depending upon the device.

You can install active venting systems such as fans or air-to-air heat exchangers. For best results, these devices should be connected to a thermostat that can be adjusted according to season and crop. Use fans to exchange air with the outside, to "dump" warm air into an attached structure, or to circulate air within the greenhouse.

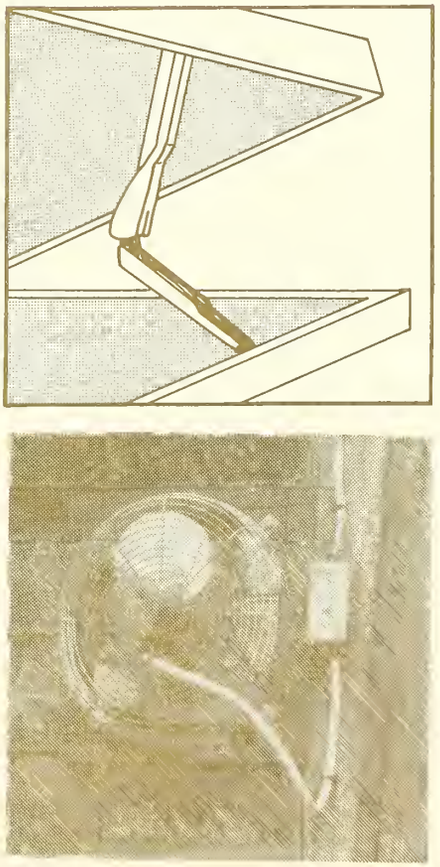


Figure 6. Passive and active vents—thermal vent opener (top) and through-wall fan (bottom).

Since ventilation with outside air is vital, especially in free-standing greenhouses used year-round, there is an advantage to prewarming incoming air in Montana's cold climate. (Attached greenhouses can usually vent-in prewarmed air from the structure to which they are attached.) Air-to-air heat exchangers prewarm incoming air by passing it through a series of compartments that share common surfaces with outgoing warm air from the greenhouse. At each end, air is directed into the appropriate compartments by a manifold. The shared "walls" are usually constructed of thin or highly conductive materials to allow the heat to transfer from the outgoing to the incoming air. With the trend to construct tighter structures to prevent heat loss, the use of air-to-air heat exchangers will no doubt increase.

The importance of proper and sufficient ventilation can't be overly emphasized. Experiments have shown that supplementary carbon dioxide well above ambient levels of 300 ppm increases plant productivity. Optimum levels of carbon dioxide for plant growth are well above the amounts available in the atmosphere. Carbon dioxide concentration in the ambient air is nature's own limiting factor. Maintaining at least normal or near normal levels of atmospheric CO_2 in the greenhouse enclosure by adequate ventilation should be one of your primary concerns. Ventilation is also an effective method to control humidity and potential disease problems in the greenhouse environment. (See Relative Humidity, below.)

The following methods of carbon dioxide supplementation should be viewed and used as just that—supplementation. You should never reduce or compromise ventilation if these techniques are used.

- **Compost in your greenhouse.** This will add CO_2 to the environment as the microorganisms involved in the decomposition process respire. A well-managed compost pile kept at 160°F is vital to prevent insect and disease problems. When decomposition is completed, no more CO_2 will be released. Therefore, periodic rebuilding of your compost pile will be necessary. (See page 24 for more about composting.)

- **Spread organic mulches,** such as straw, peanut or rice hulls, or sawdust, in the growing beds as mulch or on the floor. Again, as these materials decompose, the microorganisms respire CO_2. If you use these materials in the growing beds, a nitrogen supplement may be necessary to prevent its depletion by the microorganisms. And, as with composting, once the decomposition has ceased, you will need to replenish the mulch materials.

- **Dry ice gives off CO_2** as it evaporates. This is a safe but expensive method of carbon dioxide supplementation.

Relative Humidity

Relative humidity is the percentage of moisture in the air compared to the total amount of moisture that the air can hold at any particular temperature. Warm air can hold more moisture than cool air by volume. For this reason, excessive humidity is rarely a problem at cooler temperatures. Most plants prefer a relative humidity between 50 and 70 percent. High relative humidity (over 70 percent) coupled with warm temperatures provide an ideal environment for many bacterial and fungal diseases. Low relative humidity coupled with warm temperatures can result in increased transpiration and perhaps wilting of plants.

- **Adequate ventilation** can reduce high humidity levels by exchanging the moist interior air for the drier air outside.
- **Air circulation fans,** with polyethylene tubes properly located at plant level, will keep the air near leaf surfaces moving, thus preventing moist, stagnant conditions that could result in disease problems. However, in Montana's climate, low humidity levels are more likely to be a problem than high humidity levels.
- **Watering down walkways** and other surfaces in the mornings will help raise the relative humidity. Gravel walkways are especially good because they provide extra surface areas for wetting and don't result in muddy aisles.
- **Misting systems** operated by a humidistat or a timer are another method of raising the relative humidity. Misting can be especially useful during germination and propagation of cuttings. (Germination requires moisture. Misting prevents cuttings from losing too much water from transpiration while roots are developing.)

Growing Containers

Your choice of structures or containers in which to grow a crop will usually be determined by the crop you choose. The stage of development of a crop will also influence the type of container that is used. Beds, troughs, benches, flats, and hanging baskets are the common choices for greenhouse growing containers.

Beds are usually rectangular boxes that hold soil. They are the most common choice for small-scale greenhouse vegetable production. Beds can range from six inches high (similar to raised beds in intensive gardening) to

You may wish to experiment with "alternative" plant containers. Lewis and Frances Higinbotham of Missoula appreciate raising their own potatoes, but realize that their greenhouse sets limits on growing a space-consuming plant. The Higinbothams found that old garbage cans are perfect for growing potatoes.

Make sure you have adequate drainage in the bottom of the can, as with any growing container. Plant the seeds in a few inches of growing media in the bottom of the can. When the seedlings are visible, but haven't "popped up" yet, cover them with a few more inches of growing media. Repeat this process until you reach the top of the can. Let the plants grow to maturity. To harvest, tip the barrel over and dig in!

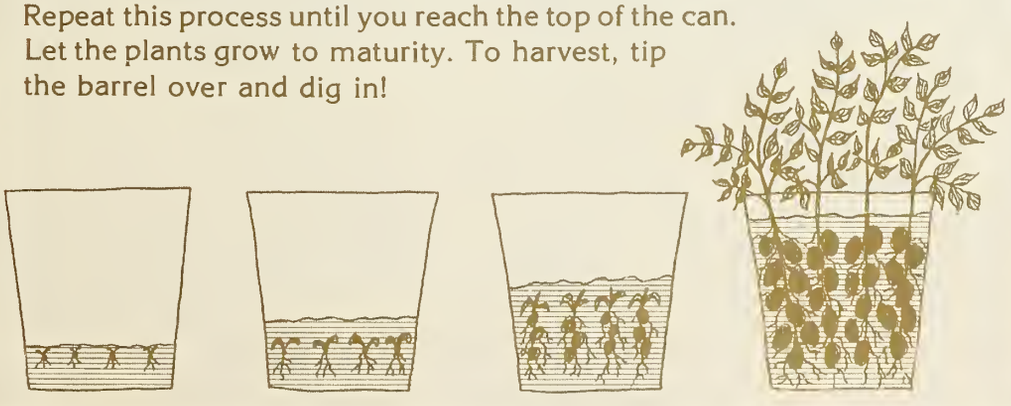


Photo by Gordon Warren, courtesy of Helena Independent Record

Figure 7. Raised beds contain valuable thermal mass, and are easier to work with than ground-level beds.

3-½ feet high. The 3-½-foot height is considered "waist height" and is convenient for working without stooping. Unless the bed will have a specific purpose, such as propagation of cuttings, germination, or growing shallow rooting vegetables, the depth should be at least 20 to 24 inches. This depth is well suited to most greenhouse vegetable crops. Deeper beds (three feet in depth) have produced greater yields when deep-rooting crops such as tomatoes were grown, and have been shown to stay warm for longer periods around the root zone. Additionally, crops grown in deep beds are higher off the ground and therefore in a warmer layer of air. Deep beds also require less frequent watering.

Troughs are similar to beds except they are sunk in the ground. Usually they are dug out and lined with boards, rock, or bricks, then refilled with soil.

Both beds and troughs should have a bottom layer of at least 6 inches of gravel or sand to provide good drainage. Raised beds with well-draining, porous soil do not need a layer of gravel or sand.

Benches are slatted wooden structures, usually at waist height, that hold pots, flats, or other small growing containers. Benches can be raised on legs or set on top of other structures such as the tops of thermal storage barrels. Benches are useful as areas for holding germination flats or containerized plants such as flower or foliage plants.

Flats, commonly used for germination purposes, are shallow wood, plastic, or pressed-fiber rectangular containers with openings (holes or slits) in the bottom for drainage.

Hanging baskets take advantage of vertical space in the greenhouse. They can be hung on hooks or from wires stretched across the greenhouse.

You will need to treat wooden structures, such as beds or benches, to prevent rotting due to frequent contact with moisture. Many wood preservative products contain phenolic compounds that harm plants and should never be used inside the greenhouse. The only safe wood treatment products you should use are copper napthanate, asphalt, and mercury- and lead-free oil-based paints. Beds can be lined with plastic to prevent moisture contact with the wood. Tom and Lisa Harpole, of Avon, line their beds with old printing tin plates. Using recycled, untreated wood boards for beds and benches and considering them to be part of the growing media is another alternative to wood treatment.

Watering Systems

Watering methods can range from simple hand methods such as using a garden hose or watering bucket to more sophisticated systems like drip irrigation, overhead sprinklers, or trickle systems. Hydroponic—soilless—production might be considered the ultimate watering system because it supplies both water and nutrients to the plants. But no matter what watering technique is used, you should consider the delivery mechanisms during the design phase of the greenhouse if possible. Automated systems involving timing devices will require electricity; wire the greenhouse to handle this. You will need plumbing for all but the simplest hand methods, which involve hauling water from a source outside the greenhouse. Install plumbing during construction. You can also run a water hose into the greenhouse from an outside faucet. However, remember that there's a chance the hose will freeze if left outside in cold weather.

Preheated water for irrigation is an important consideration in Montana's cold climate. Most plants prefer water temperatures between 60°F and 80°F.

Tap water is often colder than this, especially during the winter months. For this reason, a preheating system for cold water should be considered, particularly for a greenhouse that will be operated year round. A tank, barrel, or garbage can, placed inside the greenhouse and gravity-drained with a hose, is one preheating option. Another is to use one of your storage barrels for a preheating water container. Naturally, you must avoid using rust inhibitor in this case. Be sure that any container you use has not been a receptacle for any toxic substances. If your water source is in an attached structure and cold water can be mixed with hot water, you're in good shape.

Work Areas

Design your greenhouse interior to use the most space available for production, while maintaining a quality environment and comfortable working conditions (see Figure 8). Adequate planning for work areas and equipment storage is often neglected in solar greenhouse design. If you don't want to give up space inside the greenhouse for these functions, an attached potting shed or storage shed can be a handy addition.

Figure 8. This shady work area takes the heat off the greenhouse gardener.

Spacing of Plants: Vertical and Horizontal Arrangements

How you arrange plants within the greenhouse can have an impact on the interior environment. While maximum use of space for maximum production is the goal, overcrowding plants to achieve this goal can have the opposite effect by reducing yields. When one plant shades another, available light to the leaf surfaces of the shaded plant is reduced. Photosynthesis, and therefore growth, will be slowed or stopped. Plants that compete for light often become spindly and unproductive.

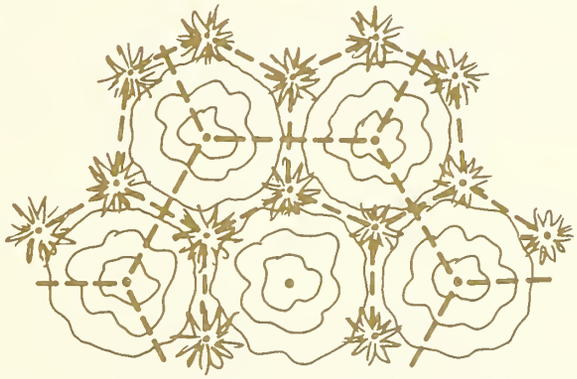
The proper spacing and arrangement of crops will benefit plant growth. Planting space can be arranged either horizontally or vertically. Crops such as tomatoes, cucumbers, melons, and peas should always be grown vertically on trellises, on strings attached to overhead wires, or on lattices. Furthermore,

these crops should be grown toward the back of greenhouse growing beds to avoid shading other crops. Since the primary source of light in the solar greenhouse is the south-facing glazing, crops should generally be arranged from the shortest to the tallest, the tallest being toward the north wall. In the warmer months when the sun is higher in the sky, and if there is no overhead glazing to admit light to the back of the greenhouse, the situation is the same because the light still enters through the south-facing glazing. Hanging baskets that don't shade other plants use vertical space effectively.

The distance between plants should be based on the potential canopy cover of the particular crop. The goal is to make use of the most space without overcrowding. The leaf canopy is the size and shape of a plant's vegetation; the cover effect is the amount of area shaded by the foliage. For example, tall plants, such as fava beans, or plants with spreading foliage, such as squash, are considered to have "dense" canopies because of the amount of ground they shade. At maturity, the plants should, theoretically, barely touch one another. An effective canopy is a good weed control technique because it shades out competitors.

Intercropping, or planting several crops together, should be carefully planned to allow the slower-growing or shorter plants a chance to get established so that the faster or taller plants don't take over.

Hexagonal or zig-zag planting



Intercropping two plants with different space requirements

Figure 9. Planting patterns that give you more growing room in your solar greenhouse.

A zig-zag or hexagonal planting scheme is the best use of horizontal space. This method is common in intensive gardening methods. Plants are arranged in a diagonal fashion to allow maximum use of the planting area. Hexagonal spacing or zig-zag spacing would be similar to Figure 9.

The most efficient use of space in arranging growing areas inside the greenhouse will depend on the configuration of the particular greenhouse. Generally, beds or benches can be arranged to run the length of the greenhouse, as islands, peninsulas, or a combination of these. Most attached greenhouses, because of their narrow rectangular configuration, use growing areas arranged lengthwise.

Using 75 to 80 percent of your floor area for production purposes is very good. But take care to include adequate space for aisles and comfortable working conditions. Aisles should be at least two feet wide. If you will be using a wheelbarrow or other equipment, the aisles should be wider. You should be able to reach all growing areas easily. Because three feet is a comfortable reach for most people, this is the recommended width for beds and benches that can only be reached from one side. If the bed or bench is accessible from both sides, six feet is an appropriate width. If ground beds wider than three feet are used, a well-placed board or flat stone can allow access to the entire bed.

Figure 10. Peninsular bedding makes it easy to work in your greenhouse.

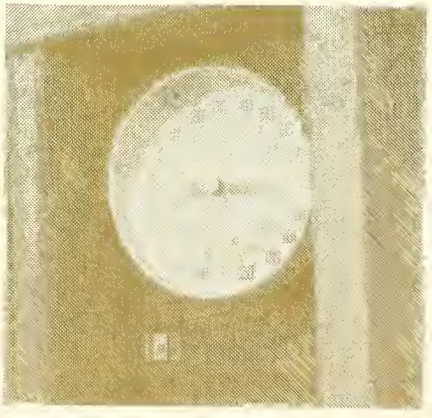
CHAPTER 4

Caring for the Greenhouse Environment

Now you're ready to turn the inside of your greenhouse into a lush, productive, and beautiful environment. With proper selection, scheduling, care, and placement, your plants will grow into wonderful food, flowers, or foliage. The possibilities are endless. Limiting your choices because of space may be the most difficult task you face. But you have favorite plants, and with food crops your taste buds can be your guides. Your choices are further narrowed as you learn which crops and varieties thrive best in Montana's northern-climate solar greenhouses.

Setting Up

Plan to spend extra hours when you are first setting up in your greenhouse. You will spend most of your time preparing your soil mix and arranging special areas for germination, seedling trays, vertical growing, tool storage, and other tasks. This is also the time to arrange any monitoring equipment you may want and to prepare your record-keeping procedures. Monitoring the high and low temperatures inside and outside the greenhouse can provide an abundance of useful information, especially if you keep good records on plant production.



Place thermometers for inside temperatures at plant level and protect them from direct sunlight to get more accurate readings. Hygrometers record humidity and should also be placed at plant level. (Instruments are available that register both temperature and humidity.) A soil thermometer is a handy and relatively inexpensive addition to greenhouse monitoring equipment. Soil temperatures have significant effects on plant growth. Having some knowledge of soil temperatures for various depths, locations, and seasons can help you understand your greenhouse environment better. Long-stemmed soil thermometers allow you to measure temperatures at depths up to 24 inches. They are also handy for reading compost temperatures.

After you are set up, plan to spend 3 to 10 hours a week per 100 square feet of growing area on horticultural maintenance—seeding, thinning, watering, transplanting, pruning, fertilizing, harvesting, observing, and troubleshooting. Running your greenhouse will be a continuous cycle (except when it sits out a season). The more extensive your record-keeping, the more time

you should plan to spend in the greenhouse. Even during times when horticultural chores are at a minimum, make regular visits to observe conditions. Fifteen minutes a day in pleasant surroundings won't seem like a chore. Detect problems early to avoid bigger problems later.

Growing Media

Your options for the greenhouse growing media include a soil mix, a soilless mix, or an inert medium like gravel or sand for hydroponic production. Soilless culture and hydroponic production require carefully controlled fertilization techniques. Your plants are totally dependent on you for nutrients in soilless and hydroponic production systems. Many commercial producers use these systems, with good results, simply because they can control the nutrient flow to the plants.

The growing medium serves several important functions in plant growth and development. It's the physical support system for the plant, the source of water and nutrients, and the control for oxygen aeration around the roots.

Aeration is a critical factor for healthy growth. Plants require an exchange of oxygen with carbon dioxide at the roots to allow the movement of water and nutrients (translocation) from the soil throughout the plant. The amount of air spaces (porosity) of the growing medium directly affects the amount of oxygen around the roots. A porous medium will have more air spaces and will drain more rapidly when watered. Growing media that do not drain well will hold water in these air spaces, preventing oxygen from re-entering. Without oxygen the roots cannot take up water and nutrients. A water-logged plant can actually suffer damage because of a lack of water; transpiration will cease, stomata will close, and the plant will wilt.

In greenhouses, where you will put some growing media in containers and water frequently (sometimes packing down the medium), use mixes that are light and drain well. You can make changes to the growing medium to improve the structure and drainage.

Soiiless mixes are usually composed of peat moss and an inorganic aggregate—sand, perlite, or vermiculite. These are common in commercial greenhouse production for two reasons: (1) sophisticated systems of fertilization allow growers a high degree of control in supplying plant nutrients, and (2) soilless mixes are usually sterile, which avoids the need for expensive soil pasteurization equipment and eliminates soil-borne diseases.

Except for germination and propagation, soilless mixes are not recommended for the novice greenhouse gardener. The fertilization program requires some precision and either time or adequate equipment (pump, timer, mixing container) for proper control.

Soil mixes are composed of topsoil amended with compost and lighteners if necessary. A well-composted soil is the basis of an organically managed fertility program.

Know the source of your topsoil; you don't want to take unnecessary chances. Your soil mix will need to be adjusted according to the texture of your topsoil. Add sand or compost to soils with a large portion of clay. Sandy soils require more organic matter. To test the texture of your soil mix, squeeze a small amount of the mix in your fist; the soil mix should not hold together.

You may want to consider renting or borrowing a portable cement mixer for mixing your soil if your growing area is large or your beds are deep. Make sure your mix is thorough, whether you mix by hand or with a mixer.

Soil Mixes

Easy Mixes

1 part topsoil
1 part compost
1 part sand, perlite, or vermiculite

or

2 parts sandy topsoil
1 part compost

or

2 parts topsoil
1 part sand, perlite, or vermiculite
1 part compost

No-Compost Mix

1 part topsoil
1 part peat
1 part sand, perlite, or vermiculite

or

2 parts topsoil
1 part peat
1 part perlite or vermiculite

Amendments: Lighteners and Conditioners

Lighteners are materials that help build lighter structural qualities in soil mixes. These materials are also the components of the soilless mixes. Lighteners are composed of inorganic matter and include sand, vermiculite, and perlite.

Sand is an inexpensive amendment for growing mixes. Coarse sand particles are good structure builders, which improve drainage and aeration. Only horticultural-grade (washed, coarse) sand should be used in mixes.

Vermiculite is made up of lightweight, heat-expanded particles. Vermiculite possesses electrically charged—"colloidal"—surfaces with a high capacity for retaining nutrients and water. Ask for the horticultural grade when purchasing vermiculite.

Perlite is heat-expanded volcanic rock and resembles small beads of styrofoam. It is also very lightweight. Again, only horticultural-grade perlite should be used. Perlite is dusty and needs to be moistened before mixing.

Conditioners not only lighten mixes but improve their capacity to hold nutrients and moisture. Conditioners are composed of organic matter and include sphagnum peat moss, compost, and manure.

Sphagnum moss is the most commonly used peat moss for horticultural purposes. It's composed of at least 75 percent decomposed stems and leaves of sphagnum moss. Aeration and drainage improve when you add sphagnum moss to mixes, but sphagnum moss adds only negligible amounts of nutrients. You can also use peat moss in soilless mixes (peatlite).

Compost is the decomposed remains of plant and animal products resulting from the activity of microorganisms under controlled conditions of heat and moisture. Compost improves the structure and moisture-retentive capacity of soils and plays a role in soil fertility. Finished compost—organic materials that have thoroughly decomposed—contributes humus to soils. Humus is a colloidal material with a high capacity for holding nutrients on its surfaces.

Manure should be well-rotted before you add it to your soil mixes. Toxic effects from the accumulation of ammonia can result when "hot" manures are used, or when soils high in manure (or compost) are pasteurized. Manure contributes to the texture and nutrient qualities of soil mixes. It is a major part of compost and is generally best cycled through the composting process.

How much CO_2 from Compost?

The amount cannot be predicted accurately because it will vary according to the materials used in each batch. But you can assume that the amount generated by a well-made pile will be substantial.

According to Clarence Golueke, a microbiologist at Berkeley who specializes in composting, the dry matter in a compost pile will lose one-third to one-half of its weight over three weeks of active composting. Nearly all (95 percent) of that lost weight is carbon that has gone off as carbon-dioxide gas. Dry matter means that the weight of the water in the composting materials is ignored; typically the water accounts for 50 to 75 percent of the total weight of the usual manures and vegetable matter.

So if you have a bin that holds 200 pounds of wastes for compost, then roughly half that is water and the other hundred pounds is dry matter. That means that about 50 pounds of carbon will go into the air as carbon dioxide over three weeks if the composting is done properly. The process will also add heat and humidity to the environment.

The compost pile should be a fast one. It should be made of manures, vegetable waste, and hay, and turned every other day for ample aeration. If much woody material like straw or wood chips is used, the pile will need a richer source of nitrogen like extra manure. Even under the best circumstances, a pile with a lot of woody material in it will only give off one-third of its dry weight as carbon dioxide. If the materials are skillfully balanced, there should be very little nitrogen lost as gas. When a good pile has cooled down from 150° to around 100°F, then most of the rapid carbon-dioxide release is over.

Finished compost like this still has carbon in it, but it will break down very slowly. Used in potting mixes or soil for planting beds, however, soil microorganisms do continue to work on it and their digestion and respiration continue to provide an important source of carbon dioxide in the greenhouse.

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cess are highly dependent on this ratio. If the ratio of carbon to nitrogen is high when compost is added to soil, the microorganisms will often "rob" the soil of its nitrogen. If the ratio is in the proper range, the compost will actually release nitrogen and other nutrients to the soil as the microorganisms die. The ideal range is somewhere between 20:1 and 30:1. This slow-release action combined with its humic qualities makes compost an important part of soil fertility programs. (There are several good books on compost and composting. A few are listed in the Recommended Reading section on page 41. Please refer to them for a more complete discussion of the composting process and how to set up a compost system.)

Other organic materials you can use to adjust soil textures include sawdust, wood chips, peanut and rice hulls, and bark. However, all these materials are high in carbon content, especially the wood products, and their use will lead to nitrogen-robbing if incorporated in soil mixes. Compost these materials first. Give special attention to adjusting the carbon/nitrogen ratio in the compost if you use these materials.

Germination

All seeds require moisture and minimum temperatures for germination. A few, such as lettuce and endive, also require the presence of light. Most vegetable seeds need temperatures of 60°F or higher—up to 95°F—for best germination results. Many vegetables, however, will germinate at lower temperatures in the 35°F to 40°F range. These are the crops like spinach and lettuce that are planted outdoors as soon as the ground can be worked. Keep all seeds moist constantly to break the seed coat and to keep the young plant from drying out.

Set up germination areas wherever the necessary temperatures and proper moisture conditions can be maintained. Greenhouses with no backup heat are sometimes too cold (especially in spring) for good germination conditions. There are several alternatives in this case.

- **Germinate seeds in your house.** Choose a warm spot free from drafts. Move germination trays into light as soon as the seedlings emerge. (Give lettuce and endive light from the beginning.) "Harden off" your seedlings by moving them into the greenhouse during the day and back to the house at night until minimum night temperatures are safely above 40°F.
- **Use propagating mats** to apply electric heat directly to germination flats from the bottom. They are very good for getting heat-loving plants like tomatoes and peppers to germinate uniformly, but they are expensive.
- **Electric heating cables** are less expensive. Use them in shallow beds specially designed for germination or propagation. Wind the cable along the bottom of the bed, then cover with sand or a light soil or soilless mix. Set flats on top of the medium so they can receive bottom heat, or start seeds and cuttings directly in the bed. You could also use a shallow bed for seeding and propagation for winter crops with shallow roots. This bed could be placed next to the thermal mass for best temperature effects in either situation.

Hot beds are shallow boxes with some source of supplemental heat such as a heating cable. Hot beds often have tops or lids that can be closed at night.

Seeding and Transplanting

Seed crops directly where they will be grown, or in flats or individual pots. Sow plants, such as melons and cucumbers, that don't take kindly to having their roots disturbed, into individual peat pots for transplanting later. Some plants won't tolerate transplanting at all. For example, carrots, beans, and peas should always be directly sown. Root crops like beets and turnips are also usually sown directly and thinned.

As mentioned in the section on Growing Media, page 22 , you'll do well to use a light soil or soilless mix for germination. Sow seeds in flats or beds at a depth of roughly two times the diameter of the seed. This is a good rule of thumb, but pay attention to individual instructions on the seed packet. With very small seeds, such as herbs, don't cover them at all when they are sown, but press them into the soil with a board or the palm of your hand.

Cover seed trays and flats with plastic or panes of glass to help retain moisture and some heat. Remove these coverings as soon as the seedlings begin to appear. All seedlings need light after they emerge.

Young seedlings will live off the food stored in the seed until they have formed their first set of true leaves. This is why a soilless medium is fine for germination, and it eliminates the possibility of soil-borne diseases. After seedlings form their first true leaves it is time to transplant—or thin. The first true leaves are those that form after the cotyledons have emerged. The cotyledons are the seed leaves—the first green on the seedling.

Transplant with a great deal of care. Young seedlings are usually transplanted into divided flats or individual pots one inch or larger to develop further before they are set in place permanently. There are great advantages of transplanting. Plants can be placed precisely where you want them. This results in better use of your production areas because of better spacing between plants and using transplants to fill in "holes" or gaps from lost or pulled plants. Choose only the healthiest, sturdiest seedlings.

When transplanting, be very careful not to disturb the root system any more than you must. Moisten the medium in which the plant is growing and where the plant is going. Gently lift the seedling by its leaves or the soil around the roots. Transfer it to its new container and firmly press the soil around the roots. Water immediately. Keep young transplants out of direct light, if possible, and keep them moist until they have recovered from transplanting.

Pets in the greenhouse can be a nuisance. Dogs have a lot of energy and can trample seeds and plants to oblivion. They love to dig into and lie down in a moist bed on a hot summer day. Cats think the greenhouse beds are custom-made litter boxes. In general, all the problems you are likely to have with dogs and cats in an unfenced garden exist in the greenhouse.

Watering Techniques

As mentioned in the section on Design Considerations, your watering system can be the simplest hand system with a hose or watering bucket, or a more sophisticated automated system. There are some obvious trade-offs in any choice. The hand methods are inexpensive but time-consuming. The automated drip, overhead watering, or trickle systems are more expensive but save time and labor. Systems without the automatic timing devices are less expensive.

Whatever type of watering system you use, keep in mind these techniques for watering.

- **Thorough, less frequent irrigations** are more beneficial to plant growth than shallow, frequent waterings. Water the containers and shallow beds until you see water running out the bottom. If you don't see water coming out, you have drainage problems either in the soil or the container.
- **Keep seed trays and seedlings moist** at all times. Recently transplanted seedlings are often misted numerous times daily in commercial operations, to keep transpiration to a minimum until roots can develop.
- **Keep an eye** on plants in containers. They dry out faster and require more frequent irrigations.
- **Use the "finger test"** to determine when to water. This can be applied to containers and beds. Push your index finger into the soil (away from plant roots in a container) several inches to feel for moisture. If it's dry, water. This is a crude but easy technique. Obviously, different plants and varying conditions will dictate a more exact approach.
- **Greenhouse beds** will generally require watering a couple of times a week in warm weather and less than once a week in cool weather. In cold, cloudy weather a once-in-two-weeks watering is normal.
- **Avoid watering** on cloudy days or late in the day. Water in the mornings if possible, and on sunny days when you can expect good evaporation rates. Standing moisture increases the chances of fungus problems. Also, water can carry diseases.
- **Preheated or warm water** (about 70°F) is less shocking to plant roots and warms the soil as well.
- **Water seed flats** with a fine mist and take care not to beat down seedlings or create puddles.

Fertilization Programs

All plants need certain nutrients to thrive. Nutrients are mineral elements necessary for plant growth. With the exception of carbon and oxygen, supplied from the air as carbon dioxide, all nutrients come directly from the growing media.

The essential mineral elements for plant growth are carbon, oxygen, hydrogen (from water), and the "macro-" and "micro-" nutrients. The macronutrients are nitrogen, phosphorus, potassium, magnesium, calcium, and sulphur. The micronutrients, or trace elements, necessary for healthy growth are iron, manganese, boron, copper, chlorine, zinc, and molybdenum. As the name implies, macronutrients are those elements needed in larger proportions for optimum growth, while micronutrients are minerals needed only in small, trace amounts.

In a soil culture these essential minerals must not only be present in the soil in the proper proportions, they must also be available to the plant. Some soils have a greater capacity to make nutrients available to plants. This ability to hold nutrients is known as the cation exchange capacity (CEC). Clay soils and soils high in organic matter have greater CECs than sandy soils. Humus, the finished product of compost, has up to 30 times the CEC of even the best clay soils.

Another important factor in nutrient availability is the measure of soil acidity—or the $_{p}H$—of the soil. The $_{p}H$ (power of the hydrogen ion) is measured

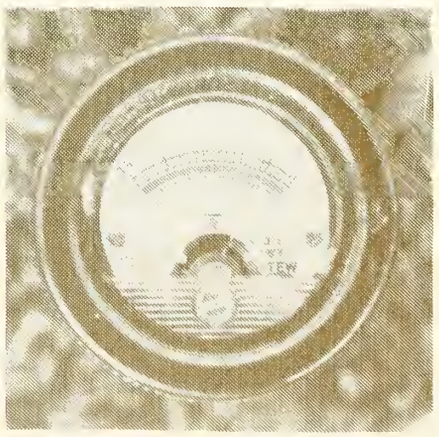


Figure 11. A soil pH gauge measures your soil's acidity level, and helps you judge how much fertilizer or nutrients to add.

on a scale of 1 to 14; below 7.0 is the acid range, above 7.0 is the alkaline range, and 7.0 is neutral. Most vegetable crops prefer a pH in the acid range from 5.5 to 7.0. A pH of 6.5 to 7.0 is the preferable range for your soil mix.

The pH affects soil nutrition in several ways:

- **The activity of soil microorganisms,** which converts organic nitrogen into available forms for plant use, can be slowed considerably in extreme pH conditions.
- **Several essential nutrients** become bound up chemically when the pH is below 5.0 or above 7.5.
- **Some of the trace nutrients**—manganese and iron, for example—will actually become available in proportions toxic to plants that have a pH below 5.0. (Generally, lime is added to raise the pH in acid soils, and elemental sulphur is added to lower the pH.)

Test your soil's pH and nutrient qualities. Soil-testing kits, pH, and macronutrient testing, as well as testing for CEC and trace elements, will help you decide how to adjust your soil.

In the greenhouse, supplemental fertilization is often necessary because frequent waterings leach nutrients from the soil, and intense production depletes soil of nutrients.

Replace nutrients on a regular basis through a soil fertility program using compost, a supplemental fertilization program, or both. Nitrogen, phosphorus, and potassium are the nutrients needed in the largest quantities by plants and therefore are the most quickly depleted in intensive production.

Organic Versus Inorganic Fertilizers

Inorganic fertilizers are chemically synthesized substances treated with acid to make them soluble. Because of their solubility, the nutrients are usually very fast acting, being immediately available in solution to the plants. Also due to their solubility, they leach very quickly from the media when watered. For this reason, many commercial producers use a "constant-feed" technique (fertilizing with every watering). Most of the inorganic fertilizers are produced by energy-intensive techniques requiring high temperatures and pressure. They are often high in soluble salts which, if allowed to build up in the soil, can be toxic to plants. There is also evidence that chemically derived fertilizers can be detrimental to soil organisms, particularly earth worms.

Inorganic fertilizers are available in precisely calculated strengths and are generally cheaper than organic fertilizers (except for homemade compost). They are easy to use and readily available. You can purchase them at garden shops, nurseries, and greenhouse supply businesses. Follow directions carefully when applying.

Organic fertilizers are naturally derived sources of nutrients. They are available in liquid and solid forms. The liquid sources are more soluble, thus more rapidly available to plants than the solid forms. The solid sources are slow-releasing compounds that meter out nutrients over a period of time.

The key to an organically managed fertilization program is the concept of a "living" soil. A well-composted soil, rich in organic matter and high in microorganism activity, supplies nutrients as the microorganisms break down the organic matter. Because plants can use only small amounts of nutrients at any one time, this provides a stable feeding program. However, microorganism activity slows down during colder temperatures. Decomposition slows

down, and fewer nutrients are available. The decomposition of solid organic fertilizers also slows down, further restricting available nutrients. But during the colder weather, plant growth also decreases significantly due to the reductions in light and temperature. The need for nutrients (and water) is reduced to "keep pace" with other plant processes.

Generally, the fertilization program in an organically managed system involves adding compost and smaller quantities of more concentrated solid fertilizers into the soil between crops.

Sidedressing is sometimes a more practical method of adding solid fertilizers to the soil, especially during crop growth or when the entire crop is not being replanted. Sidedressing means placing the fertilizer next to the plant and watering the fertilizer into the soil over a period of time.

Liquid fertilizers can be diluted and added to the soil around the plant or to the watering system. A very handy and inexpensive device for proportioning fertilizer with a hose is called the "Hozon." The Hozon attaches to the water faucet and the hose end, and has a siphon tube that is placed in the fertilizer solution. As water runs through the hose, the Hozon mixes the fertilizer solution with the water. The Hozon is available in a variety of proportioning ratios.

Some of the more common organic fertilizers include:

for nitrogen—blood meal, horn and hoof powder, cotton seed meal, fish meal, urine, and manures;

for phosphorus—bone meal, rock phosphate;

for potassium—wood ash, granite dust, seaweed;

for general and trace elements—liquid seaweed, fish emulsion, and manure tea.

Incorporating organic fertilizers into the composting operation is often the safest way to make use of the nutrients and avoid application problems. Follow directions closely when using fertilizers.

Generally, organic fertilizers are more expensive than inorganic fertilizers and more often difficult to find. But with a good composting program the amount of organic supplements can be reduced. Regular feedings with liquid seaweed and fish emulsion are advised during the "faster" production periods—spring, summer, and fall.

Crop Selection and Scheduling

Solar greenhouses are designed and built for heat, for food production, for foliage plants, for a pleasant sunroom, and for a variety of other purposes. When food production is your primary objective, you can design or build the greenhouse with a very specific use in mind—such as a seedling house, a summer crop house, a season extender, or for year-round production. For example, the ability of the greenhouse to produce year-round will depend on whether you maintain minimum interior temperatures. Only tightly constructed, well-insulated structures with adequate thermal mass or greenhouses with a backup heat source could be expected to produce year-round in Montana.

Proper crop selection and scheduling can have a real impact on the quality and quantity of production from your greenhouse. Many crops can tolerate low light levels and temperatures below freezing (some down to 0°F). These crops are logical selections for late fall, winter, or early spring production. But

other crops can't tolerate those conditions. Tomatoes need temperatures of 58°F to produce fruit, and, although it is possible to push tomato production into the colder months of November and December, the results (quantity and quality of production) probably don't justify the use of space or heat.

Schedule your crops for proper timing. Consider seasonal variations as well as maximum production and optimum environmental conditions (see Appendix 2). Successive plantings involve sowing seeds at regular intervals to produce crops on a continual basis. For some crops, such as lettuce, having a steady supply is certainly better than having your entire crop ready to eat at once. A number of crops will adapt well to a continuous or "sustainable yield" method of harvesting. The sustainable yield method involves harvesting the outer and lower leaves of the plant over a period of time. You don't pull or cut the plant, but harvest it gradually until it no longer produces an edible yield. Then replace the plant. This method of harvesting will work especially well for winter-season, leafy, green crops such as chard, kale, collards, leaf lettuce, and Chinese cabbage.

Your personal likes and dislikes of various foods, your love of flowers, or your desire to experiment with crops will affect how you arrange plantings. Of course, one of the major factors influencing the selection and scheduling of crops is the variation of seasons. You can't ignore the effects of seasonal differences in light, temperature, and humidity. Timing crops for successful completion of physical developments—like "fruiting" in tomatoes, squash, and peppers, or "heading" in lettuce, broccoli, and cauliflower, or root bulb formation in onions, beets, and carrots—will certainly produce greater yields. (What could be more disappointing than nurturing a plant into maturity only to have it freeze before it has had a chance to produce?)

Timing crops to take advantage of environmental conditions can be important. Aside from the effect of seasonal changes in the greenhouse, changing conditions are also created by the plants themselves. Changing conditions of light due to the growth of plant foliage is one factor you can plan for in scheduling crops. It's important that you time planting slow-growing or short plants to take advantage of available light before there is competition for light.

As a rule, solar greenhouses—used for growing plants—do not qualify for state or federal income tax credits. However, if your "greenhouse" is actually a "sunspace," used only for receiving, storing, and transmitting solar heat to your home, you may be able to use part of your expenses as a tax credit.

If you use your solar greenhouse to grow food or plants to sell commercially, your greenhouse may be considered a business expense.

The laws regarding tax credits and deductions are complicated. Before taking any tax deductions or credits for your greenhouse, check with a competent tax service, the Internal Revenue Service (1-800-332-6103), or the Montana Department of Revenue (444-2837).

CHAPTER 5

Pests and Diseases

For a pest or disease problem to occur in your greenhouse, there must be three things present: (1) a susceptible plant, (2) a pest or pathogen, and (3) the proper environmental conditions for it to thrive. Since you can't control a pest or a pathogen before you are aware of its presence, you must concentrate your efforts on preventing the other two variables. Prevention is always the best approach. (See Appendix 3.)

A plant under stress is always more susceptible to attack by insects and pathogens than one that isn't under stress. Plants are stressed by a lack of, or an overabundance of, certain conditions—too little light, too much water, too little room, too few nutrients, and so on. Sometimes plants that appear quite healthy are stressed. Overly fertilized plants, for example, may look healthy, but their lush, nitrogen-rich growth often attracts insects.

Controlling the environmental conditions is not always easy because different pests and pathogens thrive within a variety of conditions. For example, spider mites like it hot and dry; fungi prefer it moist and warm. But cool and moist conditions should be avoided whenever possible, because this is the least favorable set of conditions for greenhouse crops.

Prevention

Prevention by good sanitation techniques will go a long way toward controlling pest and disease problems. Prevention is widely practiced in the greenhouse industry. Mostly, it's good common sense. Here are some suggestions:

- **Keep weeds cleared** from under benches, from aisles, and from around the greenhouse. (These are potential breeding areas.)
- **Screen all openings** into the greenhouse.
- **Practice rotation planting,** if possible.
- **Pull all badly infested or infected plants,** and burn them.
- **Wash your hands** after handling infected plants.
- **Use resistant varieties,** if possible.
- **Use only thoroughly "cooked" compost.** (Minimum temperature 140°F.)
- **Keep the hose end** or nozzle off the ground. (It can pick up and quickly spread pathogens throughout the greenhouse.)

Figure 12. Don't smoke in your greenhouse. Tobacco is a source of mosaic virus.

- **Replace the top 12 inches** of soil in your beds if you have problems with soil-borne disease.
- **Don't smoke** in the greenhouse or handle plants after you've been smoking. (Tobacco is a source of mosaic virus.)
- **Wash all pots,** flats, and tools with a 10% solution of chlorine bleach and water between uses.
- **Clean your greenhouse** thoroughly at least once a year with a bleach solution. (Cover beds with plastic to avoid spills into the soil.)
- **Check plants** before you bring them into the greenhouse from the garden, nursery, or house.
- **Provide good air circulation** in the greenhouse.
- **Observe carefully;** catch problems early.

Controlling Pests

Greenhouses provide wonderful environments for pests as well as plants. The prevailing conditions and an abundance of food can make the greenhouse a very attractive place to a variety of pests.

The most common greenhouse pests are aphids, whiteflies, spider mites, scale, mealy bugs, thrips, caterpillars, and cutworms. Snails and slugs can also be problems.

Pest controls can range from the most direct methods like handpicking or smashing the pest to spraying with highly toxic chemical pesticides. Other control measures include trapping devices, homemade sprays, and botanically derived contact poisons. Biological controls take advantage of natural enemies to combat pest problems. Insect predators, parasites, and virus, bacteria, and fungi organisms are biological controls.

Biological controls are based on the "balance of nature" concept that all living creatures have natural enemies and that the host and enemy populations will reach stable populations if left to run their biological course. In biological control practices, damage from pests is tolerated up to certain threshold levels. These thresholds are often economic; damage can no longer be tolerated due to economic losses. Understanding pest and control life cycles is essential to biological management.

Biological controls have been used successfully in many greenhouse environments. However, large-scale use of biological controls is still experimental. Some of the biggest problems include finding reliable rearing techniques for these control organisms and maintaining populations—both pest and control—in the greenhouse.

Predators and parasites are the controls currently most used in tests. Predators kill their hosts directly. Parasites usually attack the host by laying eggs in its body, which kills the host when the eggs hatch. Parasites often only attack a specific host. Predators tend to be less discriminating in their eating habits.

Disease organisms, though not widely used, have good potential because they almost always attack a specific host. This would allow better control over the testing.

Diseases

Diseases are caused by fungi, viruses, or bacteria.

Fungi thrive in moist conditions and are probably the cause of most diseases that afflict greenhouse crops. Fungus-related diseases include downy and powdery mildews, fusarium and verticulum wilts, alternaria (leaf spots), and damping-off rots. Controls for fungus-related diseases include circulating air around leaf areas to prevent stagnant, moist conditions; adjusting soil $_{p}$H for soil-borne fungus problems; creating acid conditions; lowering humidity; and maintaining good sanitation techniques.

Viruses can be transmitted by insects, or on seeds, hands, or tools. Mosaic viruses are most common in greenhouses. There are no cures for viral problems; pull and burn infected plants. Controls include use of resistant plant varieties; elimination of pests that can transmit viruses (aphids are common carriers); rotation of crops; clean culture practices; and skim-milk sprays—used for prevention in European greenhouses.

Bacteria can cause rot, leaf spots, wilt, and blight, but are not as prevalent as viral and fungus diseases. They often enter plants through wounds. Controls include good air circulation, lower humidities, and sanitation practices.

Botanical Sprays

Botanical sprays are plant-derived contact poisons, and are highly effective against most greenhouse insect pests. They are very toxic to humans as well. Exercise special care (gloves, mask, and protective clothing) when applying these sprays. Because they are contact poisons, they break down very quickly (usually within 24 hours). Nevertheless, wash produce that has been sprayed with botanical poisons before eating it. The most common and available botanical sprays are:

Rotenone: Derived from cube roots, plants native to South and Central America; this kills aphids, thrips, and chewing insects.

Pyrethrum: Derived from a member of the chrysanthemum genus, pyrethrum kills thrips, whiteflies, aphids, and many other insects. It is a wide-spectrum insecticide.

Nicotine: Nicotine sprays, such as nicotine sulphate, are derived from the tobacco plant and are highly toxic. Nicotine sprays are general insecticides and are the most powerful of these three botanicals.

Figure 13. Special spraying equipment and protective clothing make your job safe and easy.

Other Comments

When combating pest problems in the greenhouse, use a "least toxic" approach in choosing your control measures. Pest outbreaks caught in the early stages can often be controlled by direct measures such as handpicking and destroying pests by burning or smashing. Always watch carefully for pests in the greenhouse. When outbreaks reach more sizable proportions try the soapy water and homemade spray approaches or, in anticipation, order the appropriate biological predator, parasite, or bacterial organism. Using biological controls can be expensive. It's difficult to keep these creatures around once they have depleted their food source. But this type of control can be highly educational. Don't expect immediate results with most biological controls; they take time to get established.

Use botanical sprays (if nothing else is working), when you feel that the damage threshold is reaching unacceptable proportions. Realize that these poisons will kill beneficial organisms as well. If properly applied, these sprays are effective against most greenhouse pests.

Conclusion

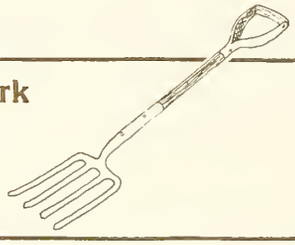
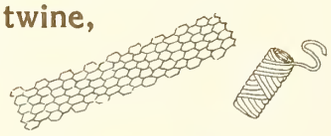
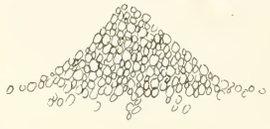
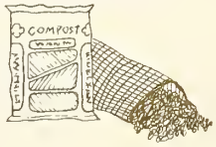
Solar greenhouses aren't for everyone. You must be willing to dedicate 3 to 10 hours each week, and a lot of your patience, to maintaining a solar greenhouse in Montana. You will have some problems that we may not have covered here. You may end up wishing you had done things differently. But you may find that the cost and effort involved in a successful solar greenhouse are far outweighed by the enjoyment you get out of your greenhouses.

Read through Appendix 4, the Recommended Reading list, for more publications that will help you develop your own system of greenhouse gardening. Appendix 5 presents sources of greenhouse materials and services.

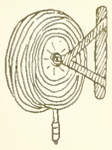
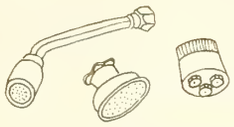
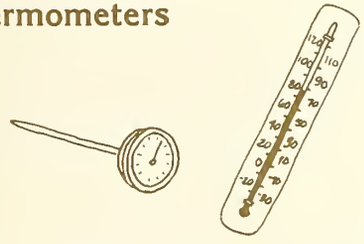
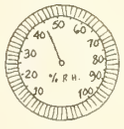
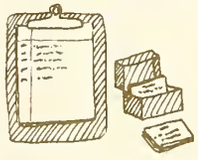
If you have any questions on, or problems with, your solar greenhouse, contact your county Extension Office, the Environmental Management Division of the Montana Department of Agriculture (444-2944), the Energy Division of the Montana Department of Natural Resources and Conservation (444-6696), or the National Appropriate Technology Assistance Service (1-800-428-1718).

Keeping a solar greenhouse is hard work; it's fun; it's exciting. Good luck!

Appendix 1: Getting Started:

What You'll Need...	And Why
Shovel	Use a shovel for the major earth-moving projects, such as initially digging beds, or clearing and leveling your greenhouse floor. Keep the shovel handy for adding fertilizer or compost to your beds.
Trowel	It never hurts to keep a couple of sturdy trowels handy for repotting jobs, or to "till" small areas of soil. Be sure to check trowels before you buy them; avoid the bargain brands that may last only a few weeks before breaking under pressure.
Spading fork 	This sturdy digging tool is indispensable for handling bulky matter like compost, or for digging up root vegetables at harvest time.
Flats and pots	Most nurseries or gardening stores handle these items. Purchase pots and build or buy flats large enough to accommodate your plants when they are fully grown. Scrub all new pots with warm, soapy water (use a mild soap), or a solution of 10% chlorine bleach/90% water and let air-dry before planting.
Wire, twine, trellis 	Use these items to aid climbing plants. Be sure that the twine you use is sturdy enough to last through at least one season.
Soil mix components	These can include sand, topsoil, peat, and others. They are used to build the soil for better plant growth.
Gravel 	Gravel aids in producing a higher relative humidity, as well as in drainage under the soil. Use it for walkways, and to aid drainage in beds.
Soil amendments 	These include bloodmeal, bonemeal, fishmeal, rock phosphate, ash, wood, vermiculite, perlite, or compost. These enrich the soil with nutrients.

What You'll Need And Why

What You'll Need...	And Why
Fertilizers	Liquid fertilizers quickly boost nutrient levels in soils. Solid fertilizers do the same, but work more slowly, gradually releasing nutrients. Manure tea and solutions of seaweed or inorganic nutrients are common examples of liquid fertilizers.
Water hose 	Water hoses are a must for your solar greenhouse unless you plan to install plumbing or sprinkling systems. Keep your hoses accessible for daily use.
Nozzles 	Your nozzles should be adjustable to accommodate misting, sprinkling, or regular watering.
Seeds	When you buy seeds, check the label or check with the retailer to assure that you will have room for the produce to grow properly, and to ensure that Montana's climate is right for proper growth of the seeds.
Thermometers 	A variety of thermostats is available to the gardener. These include soil thermometers, maximum/minimum temperature thermometers, and thermometers to keep outside the greenhouse itself in order to calculate any need for thermal or electric heat.
Hygrometer 	A hygrometer records the humidity in your greenhouse. Keep a check on your humidity level to prevent mold and fungus growth.
Notebook, clip-board, file, and index cards 	Keep these items handy in order to record such daily information as high-low temperatures, what was planted on a certain day, etc.
Soil testing kit, pH meter	Not absolutely necessary, but a must for those of you who want to keep your soil at the optimum acidity/salinity levels for plant growth.

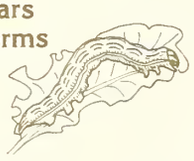
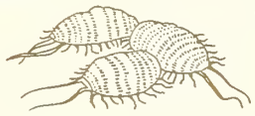
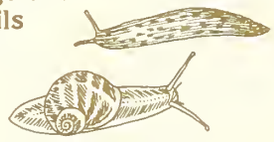
Appendix 2: Almanac for Montana's

Crop	Recommended Varieties	Location	Greenhouse Season	Days to Maturity	Optimum Temps.	Special Instructions
Beans, Bush	Provider-Bush Kentucky Wonder-Pole	Medium light, up walls	Early spring, late summer	46-65	60-70	Great on north wall of greenhouse. Train on trellises. Climbers can be used on greenhouse exterior for shade (Red Pole Beans).
Beets **Turnips**	Formanova, Detroit Dark Red	Medium light	Fall, winter, spring	50-80	60-65	Do well in shallow boxes. Plant thickly, but thin to allow root to become large. Foliage when small makes good edibles.
Broccoli	Calabrese, Italian	Medium light, cool	Fall, spring	70-150	60-65	Spatially consuming crops. Do well in pots. Transplant well into garden.
Cauliflower	Snowball,			55-65	60-65	
Cabbage	Golden acre, Chinese			62-110	60-65	
Brussels Sprouts	Jade Cross, Green Comet			90-110	60-65	
Carrots	Kinko and Juwarot, smaller varieties	Sunny	Fall, winter, early spring	60-85	60-65	Plant thickly and thin out. Slow maturers. Interplant with tomatoes.
Chinese Cabbage	Spring A-1, Michihili	Medium light	Fall, winter, spring	70-80	60-65	
Cucumbers	European-La Reine, Sandra, Toska Fo, Victory, and Marketmore	Clear side of greenhouse in spring. Back wall in winter. Can stand some shading.	Summer	60-70	65-75	Need full photoperiod. Pollinate with a small brush or let the bees in. Pull off first several feet of blossoms for better fruit set. Train on string or twine. Can be trained to climb all over the sides and roof of greenhouse.
Eggplant	Black Beauty Early Beauty	Light area	Summer	70-85	70-85	Pollinate with fingertip or small brush. Transplant from garden back to greenhouse in fall.
Leafy Greens	Leaf Lettuce Endive Kale Spinach Mustard Greens Cress Chard Collards Chicory Celtuce	Medium light, cool	Any time—makes the most sense in late fall, winter, early spring	40-85, depending on variety	60-65	Dependable winter producers. Head lettuce does not head well in greenhouse. Plant densely; thin as you eat. Leafy greens will grow in pots, on vertical surfaces, almost anywhere. Plant under trimmed tomatoes or cucumbers. Can be cut many times while growing. Will go to seed if temperatures get too hot.

Solar Greenhouse Vegetables

Crop	Recommended Varieties	Location	Greenhouse Season	Days to Maturity	Optimum Temps.	Special Instructions
Melons and Squash	Watermelon Cantaloupe Pumpkin Honeydew Crookneck Zucchini Acorn	Need light and lots of room. Front of greenhouse.	Summer, early spring	115	65-85	Trim vegetation. Grow out the vents—summer. Will cross pollinate; try to separate varieties by distance.
Onions **Scallions** **Garlic**	Bunching— Evergreen, Hardy White, White Lisbon	Medium light	Fall, winter, spring	55-75	85-120	Keep soil moist. Fresh tops are great in salads; trim regularly, start seeds in greenhouse for garden sets. Garlic is an insect fighter, either growing or ground into water solution.
Peas	Oregon Sugar Pod, Thomas Laxton	Shady areas, cool	Fall, winter, spring	58-70	60-65	Used to replenish nitrogen in soil. Four poles in corners, string lattices across.
Peppers	Early Prolific Staddon's Select	Full light area	Early spring, mid-August	Hot— 70-95 Sweet— 60-80	70-75	Adapt well to small container or beds. Pollinate with small brush. Be careful not to over water. Chile peppers do not seem to get as hot as they do outdoors; still delicious, however.
Radishes	Any	Any place	Anytime	22-40	60-65	Don't plant more than you can eat. Excellent indicator of soil viability; should sprout in 3-5 days.
Tomatoes	Earliana Marglobe Michigan Ohio Early Girl Sweet 100. Any small variety patio, cherry, pear	Front of greenhouse in spring. On back wall in winter.	Early spring, mid-August	65-100	70-75	Need full photoperiod. Pollinate by lightly tapping open blossoms or shaking plant vigorously. Train plants up strings. Trim foliage severely when infested with insects and in the fall to prevent shading of the greenhouse. Do not cut top growth until you are ready for plant to stop growing. Tomatoes are perennials and will produce for a long time. Pull suckers (found in crotch of limbs) off. They can be rooted; start in sand or vermiculite.

Appendix 3: Common Greenhouse Pests

Pests	Descriptions	What to Look For	Controls
Aphids	Soft body, pear shape, very small. May be green, brown, black, or salmon colored. Winged or wingless.	Aphids suck the juices of plants; they can be found on the underside of leaves and on succulent growing tips. Aphids secrete a sweet, sticky substance called honeydew, which attracts ants. If you have ants in your greenhouse, look for aphids.	Hand picking, soapy water sprays, home-made sprays of garlic and cayenne, botanical sprays, and ladybugs. Order ladybugs from insectories. Ladybug larvae are more voracious than the adult, and will eat up to 10 times more aphids.
Caterpillars & Cutworms 	Caterpillars are usually green. "Cabbage looper" doubles up as it crawls. Cutworms are brownish-gray, and curl into a ball when disturbed.	Large holes in the leaves or a a plant that has fallen over.	Handpick and destroy. For larger infestations, use Bacillus thurengenis, marketed as Dipel or Thuricide.
Mealy Bugs 	Appear as small clumps of cottony fiber.	Usually found in the joints between the main and lateral stems, or at the growing tips of plants. They suck plant sap and secrete a honeydew that attracts sooty molds.	In early stages, dab each mealy bug with a cotton swab that has been dipped in alcohol. Also try soapy sprays, metaphycus, and chalcid wasps.
Scale	Brownish, oval-shaped. Scale protect themselves with a shield. Common greenhouse scale are armored scale and soft scale.	Attaches itself to stems of plants, covers itself with waxy cuticle, and sucks juices from plants. Most commonly found on tropical foliage plants.	Use a cloth to wipe scale from the stems. Other controls are the same as for mealy bugs.
Slugs and Snails 	Soft bodies, gray or brown, larger ones are mottled with black.	They feed at night, leave a slimy trail, and can do a lot of damage.	Sprinkle with salt, wood ash, or lime, or handpick and destroy. Slugs and snails are attracted to warm, moist greenhouse environment. Shallow container of beer or alcohol attracts them; they drown in the liquid.
Spider Mites	Extremely small; use a magnifying glass to look for them. Most common greenhouse mites are the two-spotted mite and the red spider mite. Prefer hot, dry conditions.	Look for a very fine webbing on the underside of leaves or between stems. Damaged leaves will have a mottled appearance due to dying tissue.	Use ladybugs, lacewing, and praying mantis, which will all attack mites. Homemade sprays of vegetable or mineral oil and water (1 part oil to 20 parts water) are sometimes effective. Spray water on underside of leaves. Most effective is a predatory mite called *Phytoseiulus persimilis;* order from insectories.
Thrips	Very tiny; gray, black, or brown; fringed wings.	Scraped leaf and flower tissues. Thrips mostly attack flower crops, but are also a problem for onions and some cabbage.	Garlic and cayenne sprays. Botanical sprays are also effective.
Whiteflies	Small, white, flying insect. Size of gnats, found on the underside of leaves. Attracted to yellow color.	Whiteflies are most active when temperatures drop below 50°F. They secrete a honeydew substance that attracts a sooty mold.	Coat a yellow board with a sticky substance to serve as a trap. Shake plant, causing whiteflies to fly, and pull them from air with vacuum cleaner. *Encarcia formosa* is an effective biological control. However, its life cycle slows down at temperatures under 55°F.

Appendix 4: Recommended Reading

General Greenhouse Management

Abraham, G. and Abraham, K. **Organic Gardening Under Glass.** Rodale Press, Inc., 1979.

Debivort, L. H., et al. **An Assessment of Controlled Environment Agriculture Technology.** National Technical Information Service, U.S. Department of Commerce, 1978.

Hanan, J. J.; Holley, W. D.; and Goldsberry, K. L. **Greenhouse Management.** Springer-Verlag, 1978.

Mastalerz, J. W. **The Greenhouse Environment.** John Wiley and Sons, Inc., 1977.

Wittwer, S. H., and Honma, S. **Greenhouse Tomatoes, Lettuce, and Cucumbers.** Michigan State University Press, 1979.

Solar Greenhouse Management

Alward, R., and Shapiro, A. **Low-Cost Passive Solar Greenhouses.** National Center for Appropriate Technology, 1980.

Fontanetta, John, and Heller, Al. **Building and Using a Solar-Heated Geodesic Greenhouse.** Garden Way Publishing, 1979.

Klein, M. **Biological Management of Passive Solar Greenhouses, an Annotated Bibliography and Resource List.** National Center for Appropriate Technology, 1979.

_____. **Horticultural Management of Solar Greenhouses in the Northeast.** The Memphremagog Group, 1980.

Smith, Shane. **The Bountiful Solar Greenhouse—A Guide to Year-Round Food Production.** John Muir Publications, 1982.

Yanda, Bill, and Fisher, Rick. **The Food- and Heat-Producing Solar Greenhouse: Design, Construction, and Operation.** John Muir Publications, 1976.

Solar Greenhouse Design and Construction

A Solar Greenhouse Guide for the Northwest. Ecotope Group, 1978.

Clegg, Peter, and Watkins, Derry. **The Complete Greenhouse Book.** Garden Way Pub., 1978.

Kramer, Jack. **Your Homemade Greenhouse and How to Build It.** Cornerstone, 1975.

McCullagh, James, ed. **The Solar Greenhouse Book.** Rodale Press, 1978.

Vocational Region 10 Solar Greenhouse. Maine Audubon Society, 1978.

Yanda, Susan and Yanda, W. F. **An Attached Solar Greenhouse.** The Lightning Tree, 1976.

Gardening

Jeavons, John. **How to Grow More Vegetables Than You Ever Thought Possible on Less Than You Can Imagine.** Ecology Action of the Mid Peninsula, 1974.

Langfield, Paul. **A to Z of Greenhouse Plants: A Guide for Beginners.** Max Parrish and Co., 1964.

Moon, Doug. **Gardening for People (Who Think They Don't Know How).** Hawthorn, 1975.

Philbrick, Helen, and Gregg, Richard. **Companion Plants and How to Use Them.** Devin-Adair, 1974.

Rottenberg, Harry. **Food Gardens: Indoors, Outdoors, and Under Glass.** William Morrow and Co., 1975.

Taylor, K. S., and Gregg, E. W. **Winter Flowers in the Greenhouse and Sun-Heated Pit.** Charles Scribner and Sons, 1969.

The Facts of Light, Ortho Book Series, 1975.

Walls, Ian. **The Complete Book of Greenhouse Gardening.** Quadrangle, 1975.

Westcott, Cynthia. **The Gardener's Bug Book.** Doubleday and Co., Inc., 1973.

Whitehead, George E. **Grow Fruit in Your Greenhouse.** Faber and Faber, London, 1970.

Composting

Golueke, C. C. **Composting: A Study of the Process and Its Principles.** Rodale Press, Inc., 1972.

Minnich, J., and Hunt, M., et al., **The Rodale Guide to Composting.** Rodale Press, Inc., 1979.

Pests and Diseases

Agrios, G. N. **Plant Pathology.** Academic Press, Inc., 1978.

Jordan, W. H., Jr. **Windowsill Ecology.** Rodale Press, Inc., 1977.

Metcalf, C. F., and Flint, W. P. **Destructive and Useful Insects, Their Habits and Controls.** MacGraw-Hill Book Co., 1962.

Streets, R. B., Sr., **The Diagnosis of Plant Diseases.** University of Arizona Press, 1978.

Wescott, C. **The Gardener's Bug Book.** American Garden Guild and Doubleday & Co., Inc., 1956.

Yepsen, Robert, Jr. **Organic Plant Protection.** Rodale Press, Inc., 1976.

Periodicals

These are a few nationally distributed publications that have emphasized passive solar and solar greenhouse work.

Alternate Sources of Energy, 107 S. Central Ave., Milaca, MN 56353

Mother Earth News, P.O. Box 70, Hendersonville, NC 28791

New Shelter, 33 East Minor St., Emmaus, PA 18049

Organic Gardening and Farming, 33 East Minor St., Emmaus, PA 18049

Popular Science and **Popular Mechanics** are both giving increasing emphasis to solar and passive applications.

Solar Age Magazine, 7 Church Hill, Harrisville, NH 03450

Solar Greenhouse Digest, P.O. Box 2621, Flagstaff, AZ 86003

Magazine Articles

Armstrong, Colleen. *The Greenhouse as an Ecosystem.* **Mother Earth News,** p. 60, Nov.-Dec. 1984.

Mackie, Bill. *Solar Greenhouses in the Northwest.* Paper for the 3rd National Conference on Technological Energy Conservation, Tucson, Ariz., Jan. 1979.

Mother Earth News. *A Year in MOM's Solar Greenhouse.* **Mother Earth News,** p. 38, Nov.-Dec. 1983.

Orr, Robert, and Taylor, Melanie. *A Solar Greenhouse Borrows from the Past.* **Family Handyman,** p. 88, March 1982.

Pummill, Walt. *Let Old Sol Pay the Heating Bill.* **Countryside,** p. 25, Nov. 1982.

Schultz, Warren, Jr. *Peak Production from Solar Greenhouses.* **Organic Gardening and Farming,** p. 58, Sept. 1982.

Snyder, Rachel. *Home Solar Gardening—Solar Greenhouses for Your House, Backyard or Apartment.* (Book reviews.) **Flower and Garden,** p. 21, Nov. 1982.

Stepler, R. L. *Add-On Sunspace for Your Home.* **Popular Science,** p. 146, Oct. 1984.

Talmage, Dianne. *Add a Sunroom to Your Home.* **Family Handyman,** p. 152, Sept. 1983.

Young, John. *Instant Solar Porch.* **New Shelter,** Oct. 1982.

Related Topics

Bickford, E., and Dunn, S. **Lighting for Plant Growth.** Kent State University Press, 1972.

Brady, N. C. **The Nature and Properties of Soils.** MacMillan Publishing Co., Inc., 1974.

Knott, J. E. **Handbook for Vegetable Growers.** John Wiley and Sons, Inc., 1957.

Reports

Craft, M. A. **Winter Greens: Solar Greenhouses for Cold Climates.** Renewable Energy in Canada, Toronto, Ontario, 1983.
With the help of over 350 illustrations and photographs, this book describes the optimal owner-built, family-size, attached solar greenhouse. Step-by-step plans, charts, designs, etc.

Kent, B. **Sunspaces: Design and Build an Attached Solar Greenhouse.** Maine Office of Energy Resources, Augusta, 1982.
Instructions are given on how to design and build an attached solar greenhouse for house space heating.

Moody, R. J.; McBride, J. R.; Homer, M.; Curtis, F. A. (ed.). **Thermal Performance and Horticultural Production of an Attached Solar Greenhouse in a Severe Northern Climate.** National Center for Appropriate Technology, Butte, MT, 1982.
This paper addresses a year-long study of the thermal and horticultural performance of a low-cost (approx. $1,500) attached solar greenhouse.

National Center for Appropriate Technology, **Solar Greenhouses and Sunspaces: Lessons Learned.** Butte, MT, 1984.
The experiences of the Appropriate Technology grantees provide valuable information for building and operating better sunspaces and greenhouses.

Russell, E. **Heat Contribution from Solar Greenhouses,** 1983.
Proceedings of the Great Lakes Solar Greenhouse Conference V, 1983. Available through Chippewa Nature Center, Inc., 400 S. Badour Rd., Rt. 9, Midland, MI 48640. Write for current cost.
Climates are taken into consideration in the design of greenhouses.

Appendix 5: Sources for Materials and Services

Seeds

Burgess Seed Co.
P.O. Box 218
Galesburg, MI 49053

Harris Vegetable and Flower Seeds
Moreton Farm
Rochester, NY 14624

McFayden Seed Co., LTD.
P.O. Box 1600
30 – 9th Street
Brandon, Manitoba
Canada RFA6A6

State Nursery & Seed Co., Inc.
P.O. Box 1187
Helena, MT 59624

William Dam Seeds
Highway #8
West Flamboro, Ontario
Canada LOR2KO

Garden City Seeds
P.O. Box 297
Victor, MT 59875

Johnny's Selected Seeds
Organic Seed and Crop Research
Albion, ME 04910

Otto Richter & Son,
LTD—Herb Seed
Goodwood, Ontario
Canada LOC1AO

Stokes Seed, Inc.
737 Main St.,
Box 548
Buffalo, NY 14240

Seed Catalogs

Included here are some little-known suppliers with unusual specialties and some well-known seed houses for their more complete selection. In ordering catalogs look for seed companies familiar with your climatic conditions that cater to home gardeners.

Abundant Life Seeds Box 30018 Seattle, WA 98103	Small seed exchange for residents of the Pacific Northwest and California only.
Burpee Seed Co. 300 Park Ave. Warminster, PA 18974	Large well-known company with wide selection of most vegetables and flowers.
DiGiorgi Seed Co. P.O. Box 413 Council Bluffs, IA 51501	Forage crops, old-fashioned lettuce and other vegetables, open-pollinated corn.

Garden City Seeds P.O. Box 297 Victor, MT 59875	This Montana seed company has many varieties for northern climates.
Gurney's Seed and Nursery 2nd and Capitol Yankton, SD 57079	Unusual vegetables. Cold-weather vegetables and fruit trees.
Hart Seed Co. 304 Main Wethersfield, CT 06109	Largest selection of old-fashioned and non-hybrid vegetables. Many hard-to-find varieties available on request.
J. L. Hudson Seed Co. P.O. Box 1058 Redwood City, CA 94064	One of the world's largest selection of flower and herb seeds.
Johnny's Selected Seeds Box 2580, Foss Hill Road Albion, ME 04910	Small seed company with integrity. Carries Native American crops, select Oriental vegetables, grains, and short-maturing soybeans.
Lanark County North American Medicinal and Culinary Herbs RR 2 Amonte, Ontario	Canadian seed house, good for cold-weather areas. Ask for free organically-grown vegetable seed price list.
Meadowbrook Herb Garden Rt. 138 Wyoming, RI 02898	Bio-dynamically grown spices, herbs, teas, and herb seeds.
Nichols Garden Nursery 1190 North Pacific Hwy., Albany, OR 97321	Unusual specialties: elephant garlic, luffa sponge, winemaking supplies, herbs.
Park Seed Co. P.O. Box 31 Greenwood, SC 29647	A good selection of flowers. Gorgeous, full-color catalog available free.
Redwood City Seed Co. P.O. Box 361 Redwood City, CA 94061	Basic selection of non-hybrid, untreated vegetable and herb seeds. Expert on locating various tree seeds, including redwoods.
State Nursery & Seed Co., Inc. P.O. Box 1187 Helena, MT 59624	One of the largest garden seed distributers in Montana.
Stokes Seeds Box 548 Buffalo, NY 14240	Carries excellent varieties of many vegetables, especially carrots.
*Sutton Seeds London Road Early, Reading Berkshire, England RG6 1AB	For gourmet gardeners. Excellent, tasty varieties, hot-house vegetables.

*Vilmorin-Andrieux
4 Quai de la Megisserie
75001 Paris, France

Old, respected seed house specializing in high-quality gourmet vegetables. Catalog in French.

Arthur Yates & Co.
P.O. Box 72
Revesvy 2212
New South Wales, Australia

Specializes in tropical varieties suitable for the southern hemisphere. International seed catalog free.

*Restrictions may apply when purchasing seeds from a foreign country. Contact the USDA Animal, Plant, Health Inspection Service, 1629 Avenue D, A-5, Billings, MT 59102, or call them at 756-6283.

Soil Testing

Cooperative Extension Service
Soils Lab
Montana State University
Bozeman, MT 59715

Samples may be sent directly to Bozeman, or your county agent can send them for you. The "garden test" includes pH, potassium, phosphorus, organic matter, nitrates, and EC (electrical conductivity—for testing soluble salts). The cost is $15.50. Trace element tests are $7.50 per element.

Faust Bio-Agricultural
Services, Inc.
P. O. Box 1150
Twin Falls, ID 83301

Basic test covers organic matter, nitrogen release, phosphorus, potassium, magnesium, calcium, hydrogen, pH, CEC and salts, humus content, carbon, and nitrogen, and includes a humus chromatograph. Very thorough. Write for current prices.

Nature's Way Farm, LTD.
8401 Bollinger, N.E.
Vestaburg, MI 48891

The "garden test" includes pH, organic matter, CEC, calcium, magnesium, potash, and phosphorus. Write for current prices.

Woods End Laboratory
RFD Box 65
Temple, ME 04984

Testing includes organic matter percentage, texture, CEC, nitrogen, phosphorus, potassium, calcium, and magnesium.

Venting Devices

Solar Vent
Dalen Products, Inc.
201 Sherlake Dr.
Knoxville, TN 37922

Thermofor
Bramen Company, Inc.
P.O. Box 70
Salem, MA 01970

Resource List

Montana Contacts for Greenhouse Equipment, Materials or Contractors

NOTE: The Department of Natural Resources and Conservation does not approve or sanction any of the following companies. The list is presented simply as an initial contact source for individuals interested in obtaining further information on solar greenhouses. This list is by no means exhaustive, and individuals should seek out other sources of information.

Billings Area

Dopler Solar Construction
Pat Dopler
P.O. Box 54
Red Lodge, MT 59068
446-3021

JACO Energy Brokers, Inc.
June Cole and Larry Munyan
111 Main St., Suite 8
Billings, MT 59105
252-8242

Solar Hardware
Alan and Sandra Champlin
217 W. Main
Laurel, MT 59044
628-6108

Bozeman Area

Baerg and Sun, Inc.
1900 Nelson Rd.
Bozeman, MT 59715
586-6813

Homestead Alternative Concepts
Dave Williams
1551 Tubb Road
Belgrade, MT 59714
388-4461

Solar Mountain Co.
M. J. McBeen
Box 64
Gardiner, MT 59030
848-7280

SunCraft Appropriate Energy Alternatives, Inc.
Dale Pickard and Bob Knebel
135 E. Main, P.O. Box 1146
Bozeman, MT 59715
587-3442

Butte Area

Alexander Solar Construction
Marty Alexander
2618 Walnut
Butte, MT 59702
782-1716

National Center for Appropriate Technology (NCAT)
Box 3838
Butte, MT 59702
494-4972

Helena Area

Alternative Energy Resources Organization (AERO)
324 Fuller Ave.
Helena, MT 59601

Smit Construction
Hank and Susan Smit
904 Broadway
Helena, MT 59601
442-0233

Spencer & Co.
201 S. Jefferson
Helena, MT 59601
442-2700

Target Energy Savers
11 N. Davis
Helena, MT 59601
442-4334

Missoula Area

Boyce Lumber Co.
415 Knowles
Missoula, MT 59801
728-7100

Energy Options, Inc.
Scott Sproull and Gary Decker
240 North Higgins
Missoula, MT 59801
721-2733

Fullerton's Plumbing and Heating
401 W. Main
Hamilton, MT 59840
363-3122

Solar Structures
132 Speedway Ave.
Missoula, MT 59602
543-7446

South-Wall Builders
Steve Loken
P.O. Box 8872
Missoula, MT 59807
549-7678

Sunset Solar Construction
Dick Dill
915 Pine Hollow Rd.
Stevensville, MT 59870
777-3168

Around Montana

Decker Engineering
Glen Decker
808 Tenth Ave., S.W.
Great Falls, MT 59404
761-0362

Eastman Solar
Kirk Eastman
701 E. Main
Lewistown, MT 59457
538-2500

Solar Ray
Yellowstone Valley
Miles City, Mt 59301
232-0695

DNRC
Energy Division
Capitol Station
Helena, MT 59620

Montana Department of
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